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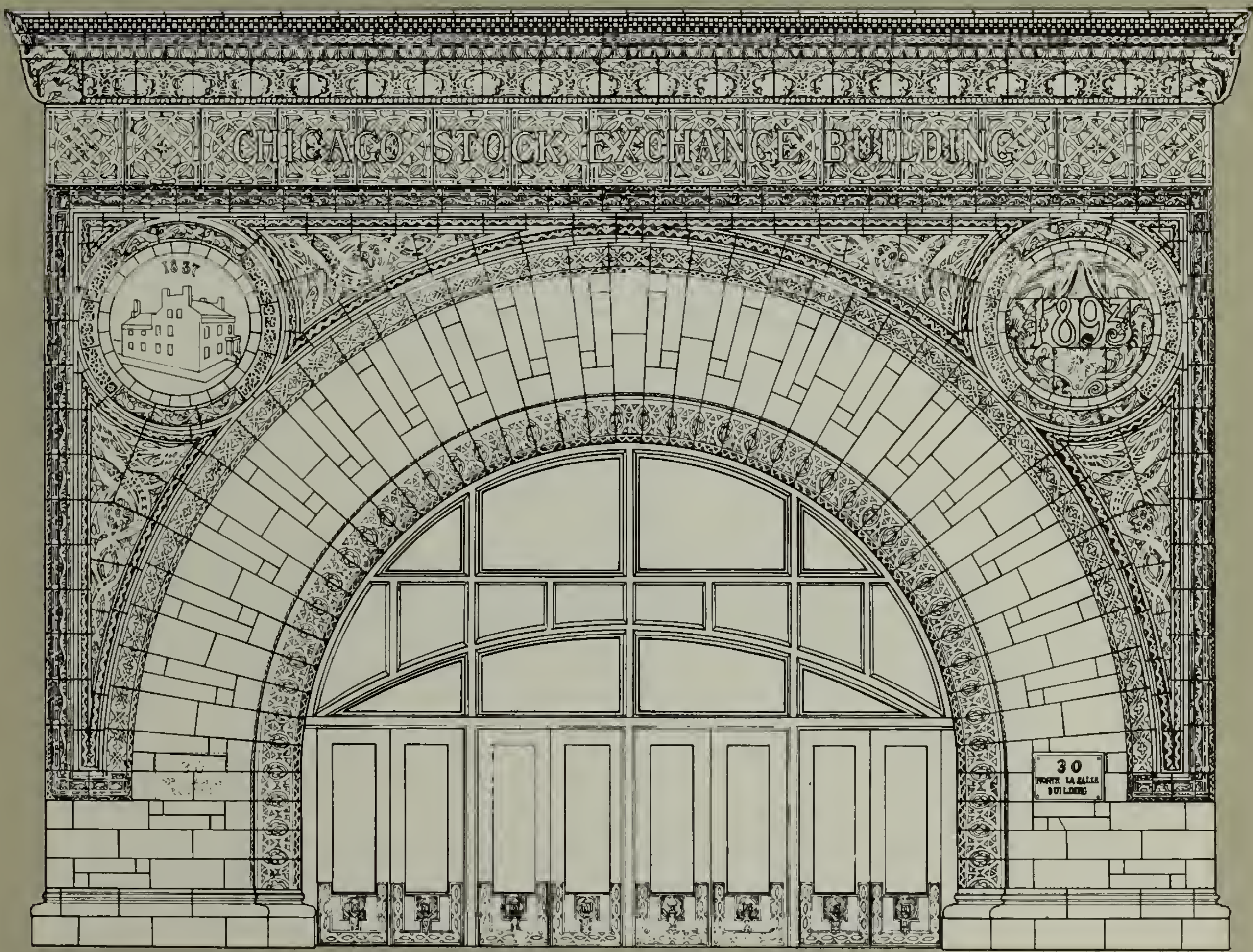
Photogrammetric Recording of Cultural Resources



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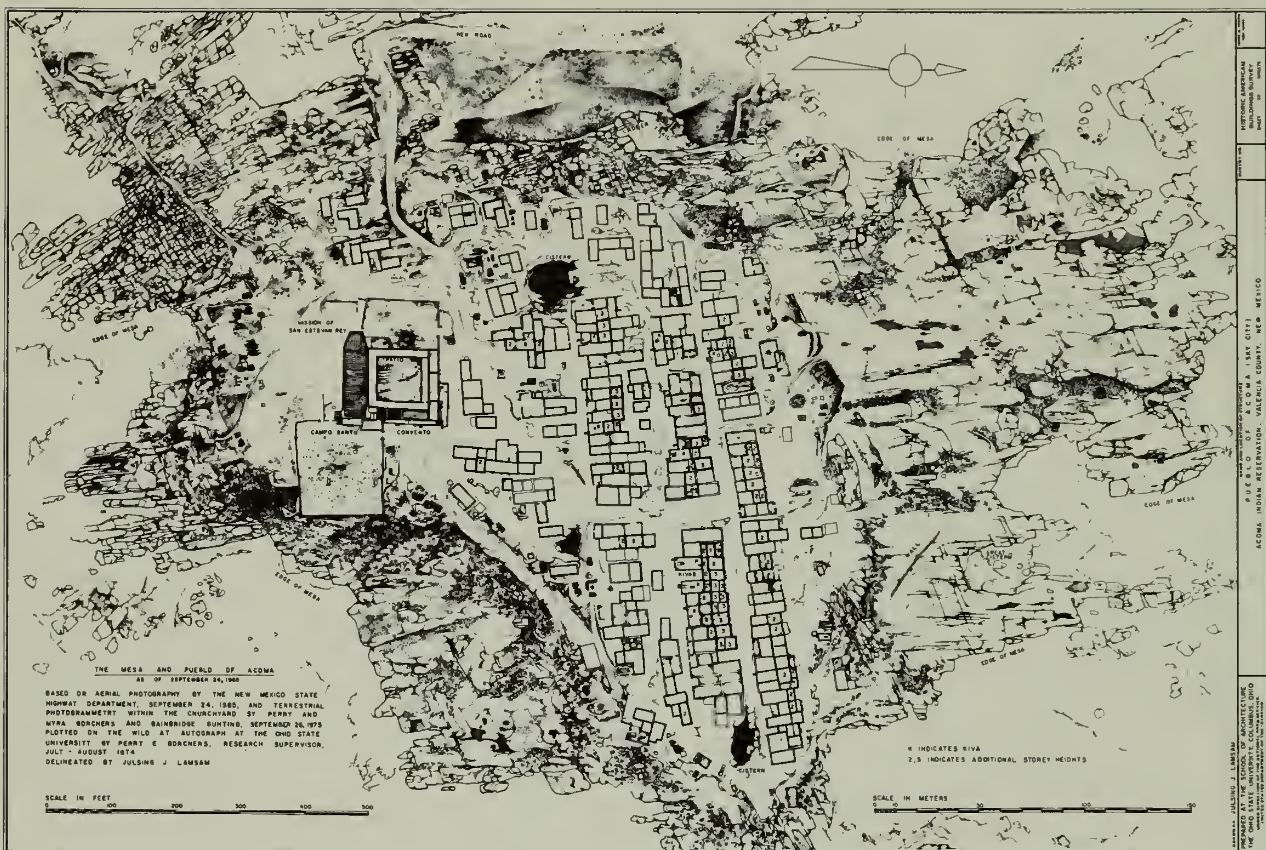

Figure 1: The Mesa and Pueblo of Acoma, New Mexico.

Based on aerial photographs by the New Mexico State Highway Department and on terrestrial photogrammetry within the churchyard. Plotted on the Wild A7 Autograph of the Ohio State University by Perry E. Borchers and delineated by Julsing J. Lamsam at the Ohio State University for HABS.

Perry E. Borchers

Photogrammetric Recording of Cultural Resources

Technical Preservation Services Division
Office of Archeology and Historic Preservation
National Park Service
U. S. Department of the Interior
Washington, D. C.
1977

Cover: Entrance Archway to the Old Chicago Stock Exchange Building, Plotted and drawn at the Ohio State University, 1971, for the City of Chicago, which contributed this drawing to HABS.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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FOREWORD

Under Executive Order 11593 signed May 13, 1971, the Secretary of the Interior was given the responsibility for developing and disseminating "to Federal agencies and State and local governments information concerning professional methods and techniques for preserving, improving, restoring and maintaining historic properties." To meet the Secretary's responsibilities, the Technical Preservation Services Division, Office of Archeology and Historic Preservation, National Park Service, is preparing a series of publications on the technical aspects of historic preservation for use by administrators, architects, and others at the Federal, State, and local levels involved with the preservation and maintenance of cultural resources.

This preliminary report, "Photogrammetric Recording of Cultural Resources," was written by Professor Perry E. Borchers of the School of Architecture, the Ohio State University. It was edited by H. Ward Jandl, Architectural Historian, Technical Preservation Services Division. Also contributing to the preparation of this report was David W. Look, Architect, Technical Preservation Services Division.

Comments and suggestions regarding additions or changes prior to final publication will be welcomed, and should be sent to Lee H. Nelson, Preservation Handbook Editor, Technical Preservation Services Division, Office of Archeology and Historic Preservation, National Park Service, U.S. Department of the Interior, Washington, D.C. 20240.

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Departmental Consultant for Historic Architecture
Chief, Technical Preservation Services Division

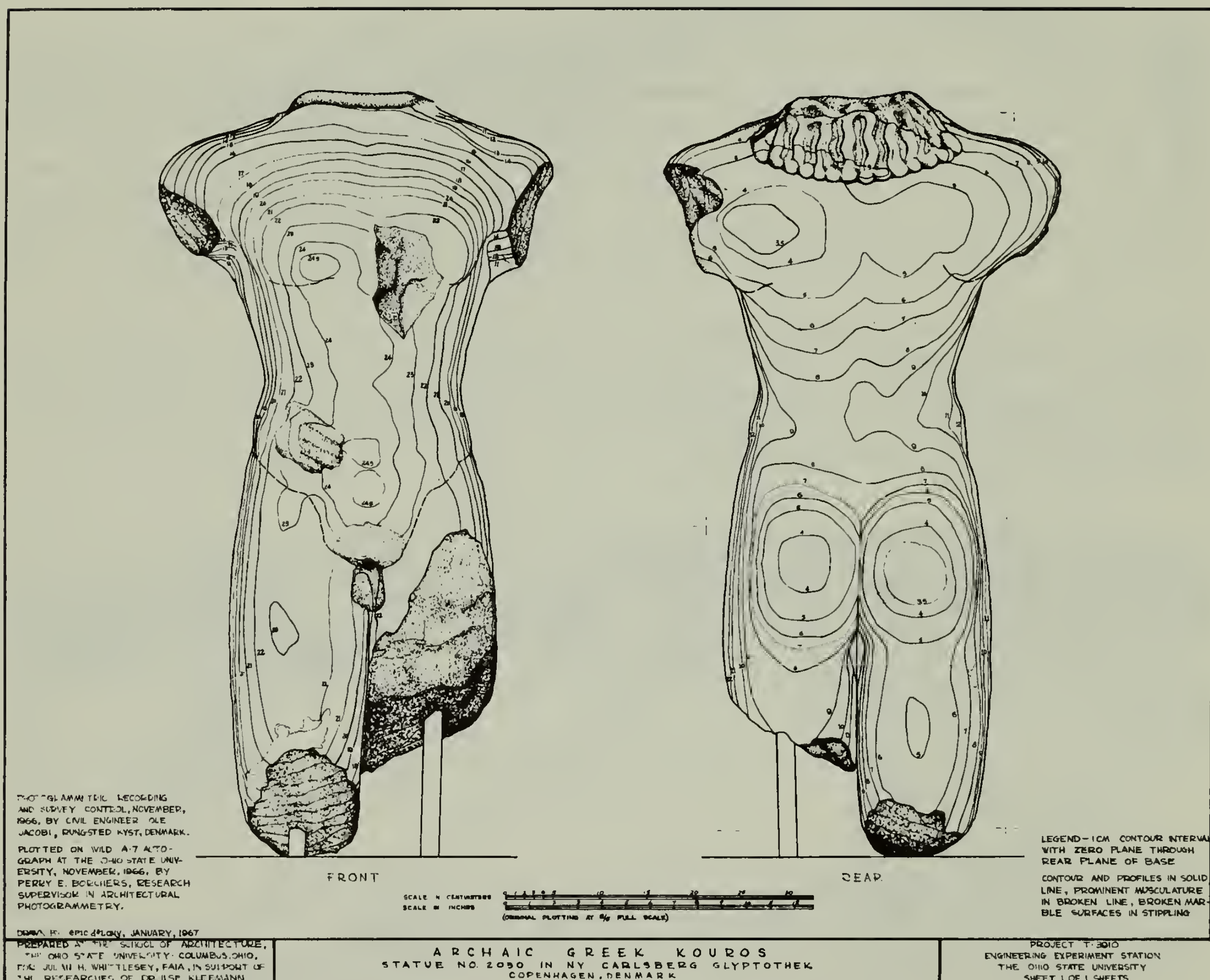


Figure 2: Topographic drawing of archaic Greek sculpture in Carlsberg Glyptothek, Copenhagen, Denmark, plotted at the Ohio State University by Perry E. Borchers and delineated by Eric DeLony, 1967, for Dr. Ilse Kleeman of West Germany.

If this sculpture were ever lost or damaged and a reproduction was desired, this drawing and the two stereopairs from which the sheet was prepared would provide invaluable information.

Introduction

WHAT IS PHOTOGRAMMETRY?

Photogrammetry is the science of measuring by means of photography. Some of its applications are as simple as this definition. Other applications of photogrammetry, however, are complex and ingenious: concerned always with the geometrical relationships between photographic images and the real objects and space recorded upon these images. Photogrammetry employs mathematical and mechnical procedures to determine and to print in digital tabulation or to plot in orthographic projection the form, the dimensions, and the location of objects from perspective views of those objects recorded photographically.

Stereophotogrammetry is one commonly used procedure, employing a pair of images—a stereopair—to create a three-dimensional, projected or mechanically viewed, "optical model." This model can be visually examined and measured in detail as if it were the real object it records.

Therefore, photogrammetry covers a broad range of techniques and, as this report will show, applies to rectified photography, reverse perspective analysis, and several other methods.

WHAT ARE THE APPLICATIONS OF PHOTOGRAMMETRY TO CULTURAL RESOURCES?

A major application of photogrammetry is the recording of cultural resources. Photogrammetric recording is a two-stage process, involving 1) photography and survey control upon the site, and 2) orientation of the photographs and measurement or plotting in the laboratory.

Because all the data is secured in the first stage of photography on the site, photogrammetry is an efficient and quick method for recording structures before their imminent demolition or collapse. A typical example of how quickly photogrammetry can be employed to record an endangered structure is seen in the recording of the ornate Spanish Revival Casa Loma Hotel in Coral Gables, Florida. The recording project was undertaken by students of Miami-Dade College just one week before the hotel's scheduled demolition.

When in 1959 it appeared that the molded plaster ceiling in Congress Hall in Philadelphia might collapse before restorers could save it, the National Park Service commissioned the Ohio State University to have a team photogrammetrically record and draw the endangered portions. During demolition of the Old Stock Exchange Building in Chicago in 1971, original Louis Sullivan ornamentation was uncovered above a suspended ceiling in the former Stock Exchange Room. The Art Institute of Chicago commissioned Perry and Myra Borchers to record the room photogrammetrically, while demolition continued elsewhere, so that drawings could be prepared for the reconstruction of the room in a new wing of the Art Institute.

Although these last two projects were carried out at some risk to the photogrammetric teams, there is generally less personal danger to members of photogrammetric teams than to teams employing hand measurements. Tall buildings and structures with difficult or dangerous access are especially appropriate for photogrammetric recording. Physical contact with unstable structures can be avoided. Scaffolding can be eliminated.

The second stage of photogrammetric recording is the orientation of the photographs and their measurement and plotting in the laboratory. This is the more costly stage of photogrammetric recording and one that may be postponed, awaiting available funds or the immediate need for detailed drawings.

The exterior of the Old Stock Exchange Building in Chicago was recorded by an Ohio State University photogrammetric team in 1963, and at that time two drawings were prepared. In 1971 one of the original glass-plate stereopairs was reoriented and plotted at a much larger scale to provide a drawing that the City of Chicago commissioned to aid in storing and future reassembly of the great entrance archway of the Stock Exchange (figure 24).

The orientation of the photographs or stereopairs in the laboratory establishes a coordinate system for measuring and drawing the optical model. Hence, photogrammetry is an efficient system for recording buildings and groups or portions of buildings that are architecturally ornate, complex, or irregular, in situations where it is difficult to recognize or establish a coordinate system for measurement on the site. Photogrammetry was used, for example, in 1961 to record and draw the facades of Thomas Alva Edison's ornate Victorian home, "Glenmont," in East Orange, New Jersey. These drawings established the major dimensions and heights on which to base more detailed drawings used in the restoration, repair, and strengthening of the structure. The Indian pueblos of the American Southwest—built upon irregular sites, with house clusters irregularly aligned, and with occasional sculptural masses of buttresses or collapsed structure—have been ideal subjects for photogrammetry.

This same coordinate system of the photogrammetric plotting instrument is readily employed in topographic contour drawings. Such drawings are regularly used to express ground forms, and can be used as easily to record deformations, sags and bulges in walls, domes, and vaults that disturb the geometry of architectural structures. Topographic drawing is often used to convey the form of sculpture, as shown in figure 2. Prepared in 1966 at the Ohio State University for Dr. Ilse Kleeman of Germany, this drawing illustrates the first step in the transition from the rigid symmetry of Egyptian sculpture to the natural forms of classical Greece.

Other major applications of photogrammetry to architecture are concerned with structural problems and exploit the advantage of recording thousands of points upon a structure simultaneously. Measuring the changes occurring from one moment of photography to another can determine the rate of erosion associated with "stone disease." With special care, even the small movements caused by thermal change can be recorded, discovered, and measured in complex architectural structures. Structural problems in monuments become obvious. A recent photogrammetric survey of the Pantheon in Paris has shown how the distortions produced in the lower portions (during construction between 1764 and 1790) were compensated for by the architect in the upper portions of the building.

When a Federal, federally assisted, or federally licensed undertaking appears likely to substantially alter or demolish a property listed, or eligible for listing, in the National Register, it becomes the responsibility of the involved Federal agency, under Executive Order 11593, to make records, including measured drawings, photographs, and maps, of the property. Because these documents may be eventually deposited in the Library of Congress for permanent reference, as a part of the Historic American Buildings Survey (HABS) or the Historic American Engineering Record (HAER), it is important they meet National Park Service standards. Photogrammetry can provide Federal agencies with a quick and efficient means of recording cultural resources under their jurisdiction or control; it has been used successfully in several cases. In late 1974, prior to its demolition using federal funds, St. Mary's Seminary Building in Baltimore, part of a National Historic Landmark complex, was recorded by Perry and Myra Borchers and a photogrammetric team.

National Park Service principles and standards for recording historic architecture are discussed in detail in Harley J. McKee, *Recording Historic Buildings* (Washington, D.C.: National Park Service, 1970).

WHAT ARE THE LIMITATIONS OF PHOTOGRAMMETRY?

In photogrammetric projects, only what appears in a photograph, and often, only what appears simultaneously in two photographs, can be measured and drawn. Accordingly, the ease of securing photographic coverage filled with significant detail determines the efficiency of architectural photogrammetry when compared with other means of measuring buildings. Since the character of buildings, the architectural elements of special interest, the conditions of the site, and the requirements for accuracy of measurement vary greatly from site to site, methods of recording buildings by hand measurement and by architectural photogrammetry should be considered complementary rather than mutually exclusive. Although a single stereopair may be able to capture 95 percent of the "orthographic projection" of a complete building facade, photogrammetry may thereafter be relatively inefficient for recording the remaining 5 percent. Each additional stereopair, made necessary by cramped conditions on the site or by foliage or projecting elements covering a portion of the architecture, multiplies the time on the site needed for photography and the establishment of "survey control" (discussed in greater detail on p. 25). Each stereopair may also require two or more hours of an operator's time for orientation on the plotting instrument before any drawing can commence. If the concealed areas are accessible, for instance, behind ground shrubbery, hand measurement may be more efficient to complete the missing portions of the orthographic projection. The time and cost of establishing adequate survey control increases markedly when requirements of accuracy, such as those desired in measuring structural movements or surface deterioration, become more demanding.

It is possible, with recent developments in photogrammetric instrumentation, to put everything recorded on the two photographs of a stereopair onto a two-dimensional **orthophoto.** Often, however, the photographs contain extraneous or disturbing detail, debris, utility wires, and ivy. The process of deciding what deserves to be extracted from the photograph and drawn upon paper is called **photo-interpretation.** This demands recognition of objects or situations in photographic images. If the drawing is to serve an architectural purpose, either as an archival record or as a basis for preservation planning, it should be prepared or supervised by someone with a thorough understanding of building and construction techniques.

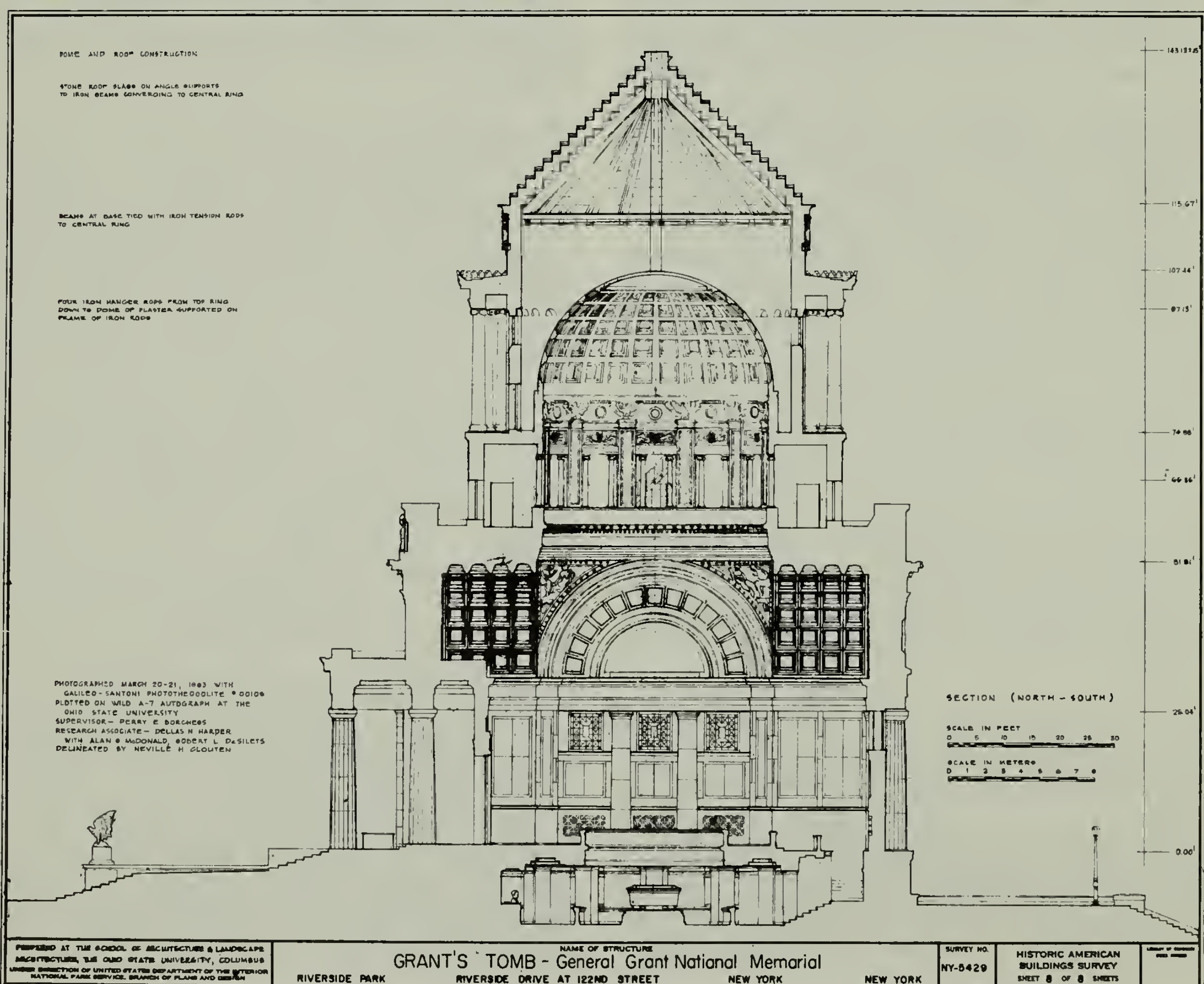
Several universities are interested in entering the field of architectural photogrammetry and have undertaken research projects; and a few private companies have the equipment and ability to undertake terrestrial as well as aerial stereophotogrammetry. Although such organizations can afford to invest in sophisticated photogrammetric instruments, their success in architectural photogrammetry ultimately depends upon a close liaison with an architect supervisor, an ability to recognize the elements of architectural importance whether expected or not, and an ability to provide the expressive touch of architectural delineation.

Photogrammetry differs from hand measurement in depending upon only a few selected dimensions taken at the site to provide scale and orientation. The final drawings usually lack many dimensions often incorporated into drawings prepared from notes of hand measurement. The coordinate counters of the plotting instrument, however, may be read to calculate closely any relevant architectural dimension; dimensions need not depend upon the accuracy of the draftsman and of his drawing. Typically, the slight discrepancies evident in survey control dimensions, or in repeated readings at a single point, can be used to calculate a "standard error," thus giving a measure to the accuracy of the whole photogrammetric procedure. In major dimensions of historic buildings, with terrestrial photogrammetric procedures and survey control as described hereafter, the standard error has typically been about 1 part in 1,200. In aerial photography, from 1,500 feet above the subject, the standard error in determinations of height of structure can be as much as 6″, amounting to the width of the drafted line at a scale of 1″=30′. This error will sometimes leave doubt, for example, about whether the projecting beam ends—vigas—of an adobe building are square or round, and it can be unsatisfactory ac-

curacy for large-scale drawings of individual buildings. On the other hand, the photogrammetric procedure immediately makes evident any common blunder in hand measurement—even in the survey control—such as misreading a tape upside down and recording a dimension 1′ or 9′ more than the actual.

In weighing the merits of traditional recording techniques and the newer photogrammetric methods described in this report, the reader may realize that a comprehensive recording program can be efficiently developed and carried out by combining the advantages of both techniques. Figure 3 illustrates how photogrammetric and hand measuring techniques can be combined to produce a finished detailed drawing. It shows a section drawn through General Grant's Tomb in New York City. The outer section line was drawn from exterior photogrammetric stereopairs, except for the concealed balcony and roof lines, which were measured by hand. The inner section was composed of plottings of level stereopairs, inclined stereopairs, and vertical stereopairs taken at main floor level and at upper balcony levels. The crypt was largely recorded by hand measurement and by film stereopairs with what would be considered nonphotogrammetric cameras. The space above the inner dome and below the roof required hand measurement, counting of stone courses, etc., for the completion of this section drawing.

Figure 3: Drawing of Grant's Tomb—General Grant National Memorial, New York, New York. Measurements for this drawing were obtained using both photogrammetric and hand-measuring techniques. Prepared at the Ohio State University for the National Park Service.



Hereafter, this report is divided into two parts: the first outlines the history of photogrammetry and the geometrical principles and methods involved, while the second is concerned with applying photogrammetric techniques to actual recording and restoration projects. Several case studies are described and illustrate a variety of photogrammetric techniques that can aid in recording, preservation, and restoration of cultural resources.

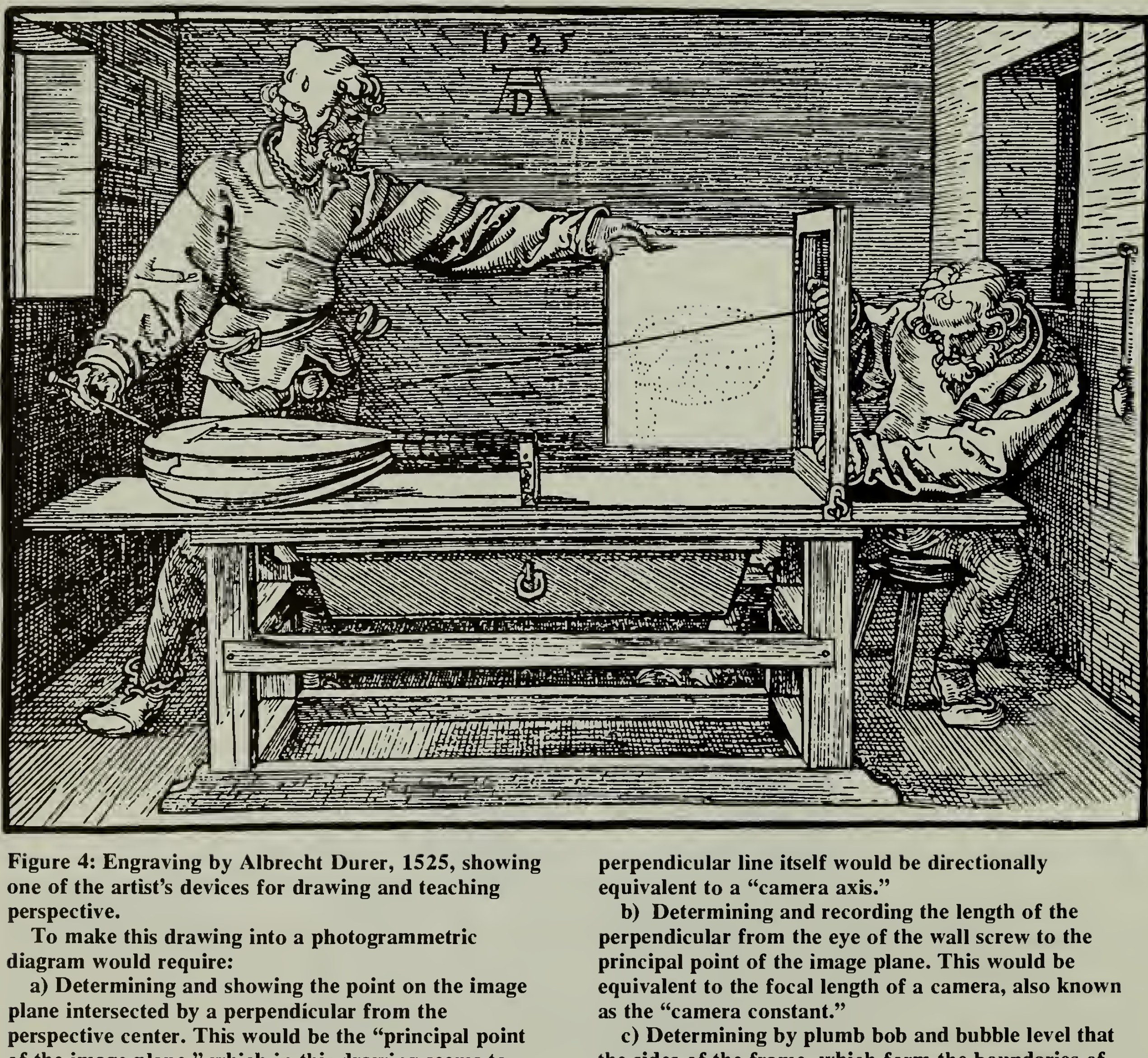


Figure 4: Engraving by Albrecht Durer, 1525, showing one of the artist's devices for drawing and teaching perspective.

To make this drawing into a photogrammetric diagram would require:

a) Determining and showing the point on the image plane intersected by a perpendicular from the perspective center. This would be the "principal point of the image plane," which in this drawing seems to lie just within the upper boundary of the frame. The perpendicular line itself would be directionally equivalent to a "camera axis."

b) Determining and recording the length of the perpendicular from the eye of the wall screw to the principal point of the image plane. This would be equivalent to the focal length of a camera, also known as the "camera constant."

c) Determining by plumb bob and bubble level that the sides of the frame, which form the boundaries of the image plane, are truly vertical and horizontal.

History and Basic Principles

The science of photogrammetry is based on the geometry of central projection. This is the geometry of perspective drawing and of the camera obscura, two methods of graphic recording that preceded, by several centuries, the photochemical development of the silver image of present-day photography.

The historical background of this science dates to the Rennaissance discovery of the laws of perspective. In one of a series of engravings, Albrecht Durer, ca. 1525, illustrates some major principles of the geometry of central projection are illustrated. (figure 4).

Durer's drawing represents lines of sight—or light rays—by a cord tied to the tip of a spike held by the demonstrator to a series of points on a musical instrument. The eye of the wall screw through which the cord is drawn tight by a hanging weight is the perspective center—or point of central projection. An assistant measures x and y coordinates where the cord passes through a frame representing the image plane. He then records these coordinates on the actual image plane, which has been swung to one side.

The geometry of central projection is also diagrammed in figure 14. Here, light rays from a real object (in this case, resembling the early Federal-style mansion of Adena at Chillicothe, Ohio) pass through the central point, or **perspective center** of each camera lens, striking the image plane in its **negative position** within the camera. In perspective drawing, or in viewing a photographic print or positive transparency, lines of sight from the eye to the object strike a **picture plane** in **positive position** between the eye and the object (or in the case of a small object. They may occasionally be projected beyond the object to a picture plane behind it). Figure 14 also indicates the steroscopic intersection in object space of corresponding lines of sight through the perspective centers of two camera stations. This is the geometric basis of stereophotogrammetry.

About a generation after the demonstration of the principles of perspective by Albrecht Durer came the development of the **camera obscura**: a dark chamber (**camera:room**) with a pinhole or lens through which an image of exterior, illuminated space was projected onto an interior surface. The camera obscura was widely used by Baroque and Rococo artists in the 17th and 18th centuries to produce accurate perspective in drawings and paintings. The camera obscura could be large enough to house an artist in darkness while he traced an inverted image projected through a pinhole or lens in the opposite wall onto a frame stretched over one interior wall, or it could be an easily transportable tent with a pole mounted lens above a hooded drafting board at which the artist sat. The camera obscura could also be a small box in which the image projected through the lens was reflected by a mirror on to the underside of a transculent surface over which the artist could trace.

One panoramic drawing of Stockholm ca. 1695, when tested photogrammetrically at the Swedish Royal Institute of Technology, revealed such accurate angular perspective at existing church spires and known locations of former castle and defensive towers to indicate it was produced within a portable camera obscura at a specific site overlooking the city. Many optical illusions of ar-

chitectural structure and of landscapes painted on Baroque and Rococo cylindrically or spherically curved ceilings could have been produced most efficiently—and therefore most probably—within a camera obscura. Where the camera obscura has been employed, photogrammetric data may be secured from the paintings and drawings produced. Similarly historic photographic negatives on glass plates may also provide photogrammetric data, although they were taken at a time when photogrammetric use of them was never anticipated.

The formal beginning of the science of photogrammetry is accredited to Colonel Aimé Laussedat of the French Corps of Engineers in 1850, shortly after the Parisian painter Daguerre succeeded in fixing "heliographic pictures" on silver-plated sheets of copper. Laussedat demonstrated a system for drawing fortifications and other buildings in orthographic projection by graphically plotting the intersections in "object space" of corresponding lines of sight recorded in photographic images taken at two or more camera stations (figure 5). This method of **plane table photogrammetry** is similar in principle to primitive military surveying, but has the advantage of recording innumerable lines of sight with a single exposure on photographic emulsion.

Under the direction of the German architect Albrecht Meydenbauer, the *Messbildanstalt* in Berlin began in 1885 to systematically collect photogrammetric records of architecture consisting of multiple photographs of single structures from widely separated and carefully surveyed camera stations. The strongly convergent intersections of corresponding lines of sight from the camera stations to architectural elements on the buildings permitted graphic methods of plotting architectural plans and elevations. The disappearance of this collection at the end of World War II prompted many Western European countries to undertake comprehensive recording programs of their art and architectural treasures.

The techniques of stereophotogrammetry (described in detail later), developed by the Austrian professor Eduard Dolezal at the beginning of the 20th century, were greatly advanced during World War II. Increasingly precise plotting instruments, first used by the military in aerial photography, were equally adapted for the recording of historic architecture. Photogrammetry became a strong and viable alternative to traditional techniques of hand measurement.

By 1956 the Belgians had recorded a large part of their architectural heritage by photogrammetry, and the Institut Géographique National of France had started large-scale recording of ancient Egyptian architecture before the buildings were inundated by water from the Aswan Dam. In 1956 the first tests of architectural photogrammetry in the United States were made at the Ohio State University, and since then many photogrammetric projects at the university have been devoted to recording structures for the Historic American Buildings Surveys of the National Park Service and other agencies and organizations. In 1968 the International Committee for Architectural Photogrammetry was formed jointly by the International Council for Monuments and Sites (ICOMOS) and the International Society of Photogrammetry (ISP).

The examples and applications described hereafter demonstrate the versatility of photogrammetry in recording cultural resources. Further information on the development of photogrammetry may be found in H. Sholer, *The General Lines of Evolution of Photogrammetric Techniques and Instruments* (London: City University, Department of Civil Engineering, 1973).

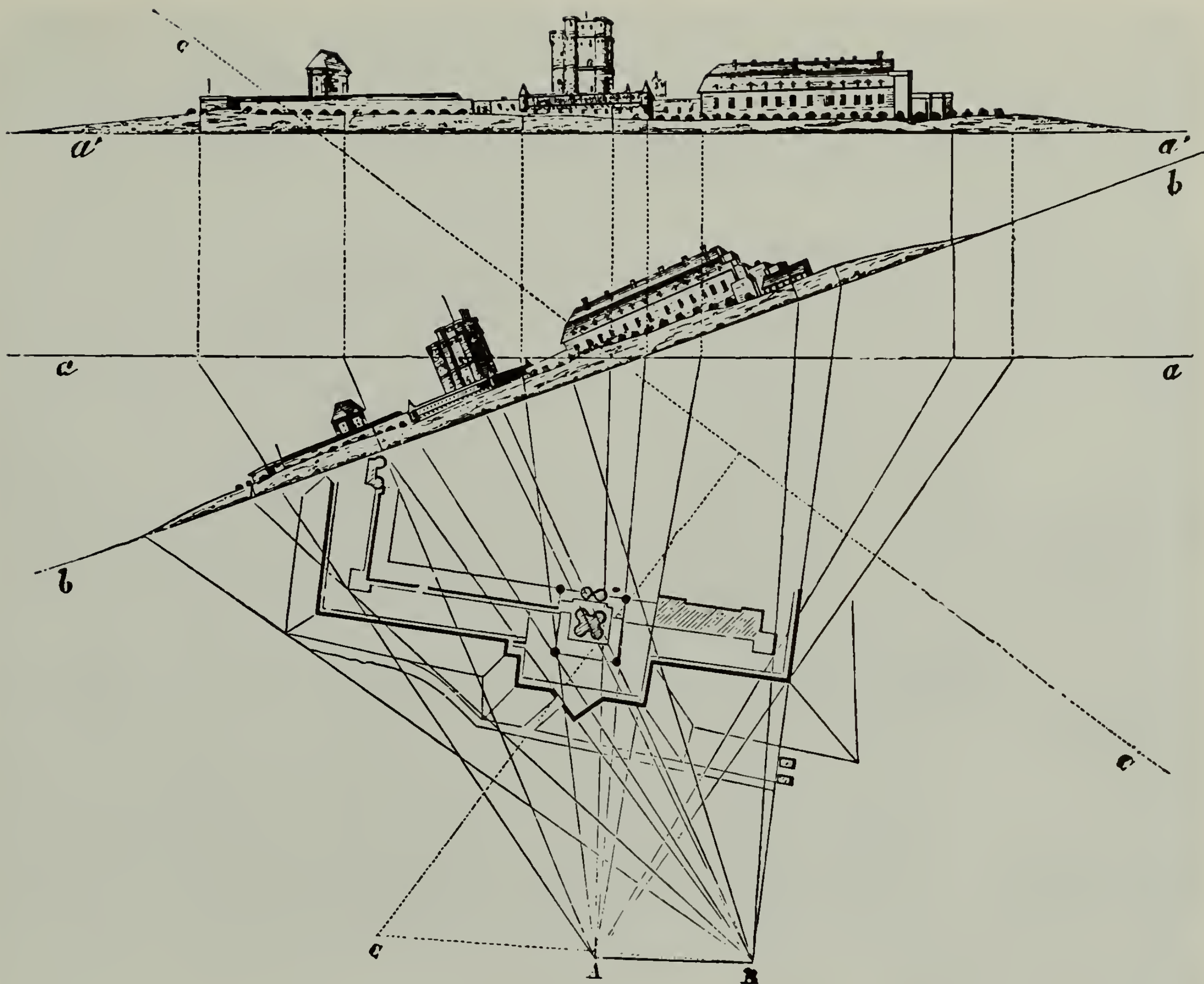


Figure 5: Engraving showing Colonel Aime Laussedat's drawing of the site plan of the Chateau de Vincennes from graphic intersection of sight lines in perspective views photographed from widely separated camera stations, 1850. Institut Géographique National, France.

Techniques and Applications

As the Introduction indicated, photogrammetry applies to a wide range of techniques, some simple and less accurate, using only a single photographic image; others sophisticated and accurate, employing precise instruments, complex adjustment calculations and many photographs. This chapter will discuss applications of photogrammetry to cultural resources and ways to secure the most useful and complete details and measurements for the least effort, time, and cost. The examples described are divided into two categories:

1. Single pictures, or mono-photogrammetry, including examples making use of reverse perspective analysis.

2. Stereophotogrammetry, including terrestrial and aerial photography.

EXAMPLE 1: RECTIFIED PHOTOGRAPHY OF FLAT SURFACES

The simplest application of architectural photogrammetry is the taking of essentially perspective-free photographs, wherein the image plane is parallel to a flat surface, such as that on a building facade or a ceiling (figure 6). Where there is considerable surface detail of jointing or grain or mosaic or painted ornament, this photography can be printed and enlarged to a **convenient architectural scale** and used as a basis for working drawings, surveys, and feasibility studies. By printing enlarged rectified photographs on photo sensitive drafting film, it is possible to transfer the photographic image onto an actual tracing. Dimensions and other notes can then be added directly to the tracing. Rectified photography, when carefully done, is an efficient means of recording complex surface detail and field observations.

Reasonable accuracy in rectified photography depends upon the validity of whether:

1. The architectural surface to be recorded is essentially a plane, and the depth of surface detail is shallow, as in the case of the Lemon Building, Washington, D.C. (figure 6).

2. An accurate linear measurement is recorded with the object to establish scale for the photograph and for the drawing.

3. The camera lens is essentially distortion free. (Note that some expensive lenses with large diaphragm openings and consequent high speed are inappropriate for architectural work because of their distortion of straight lines in architecture.)

4. The camera axis is essentially perpendicular to the architectural surface and the image plane is essentially parallel to the architectural surface.

Securing exactly scaled photographic enlargements to substitute for drawings requires skilled laboratory techniques and expense, but if the structure is of a material such as adobe, in which fine detail is absent and great accuracy of measurement is not required, a simpler variation of this method of rectified photography, making use of control marks, equidistant camera stations, and overlapping photographs, may be employed. This variation is described in figure 7.

Figure 6: The Lemon Building, Washington, D.C., demolished for the enlargement of the American Institute of Architects headquarters behind the Octagon Building, is an example of an excellent subject for rectified photography or orthophotography. The carved brick ornamentation could be reproduced in true-scale orthographic projection with full photographic texture. Photogrammetric stereopairs taken by Perry E. Borchers for HABS.

Techniques and equipment used in rectified photography are described in greater detail in *Rectified Photography and Photo Drawings for Historic Preservation* by J. Henry Chambers (Washington, D.C.: National Park Service. 1973); and "Scaled Rectified Photography on Site," by William B. Hockey *Bulletin* (vol. VII, no. 3, 1975) of the Association for Preservation Technology.

EXAMPLE 2: LABORATORY RECTIFICATION OF PHOTOGRAPHY OF ESSENTIALLY FLAT SURFACES

When space at the site is cramped so that the camera axis must be angled or inclined to the subject to achieve complete photographic coverage, the resulting photographs will have perspective distortion of the architectural planes. Under such circumstances, onsite photo rectification cannot be employed to gain accurate orthographic data, and the perspective projection of the architectural surface on the image plane must be corrected by laboratory rectification of the photograph (figure 8).

This method requires taking accurate dimensions between four well-marked control points, or targets, arranged in a large, regular quadrangle upon the surface being photographed. (Target

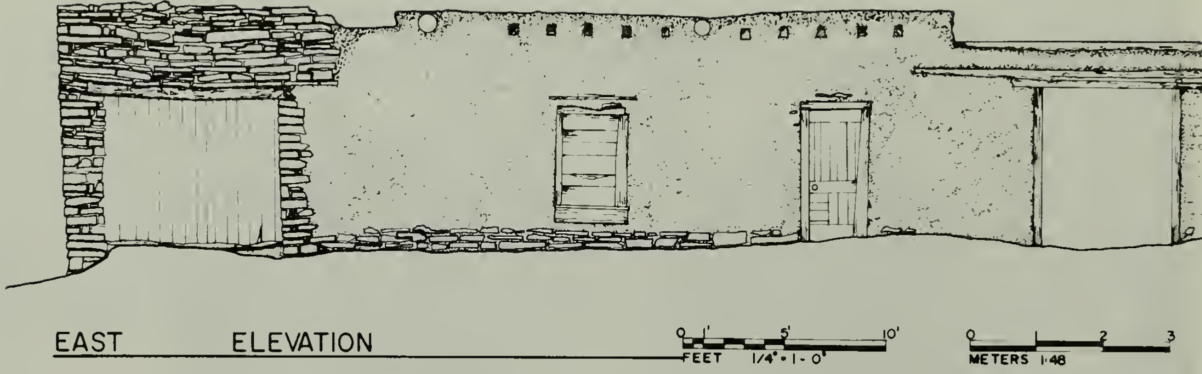


Figure 7: Rectified photography of essentially flat surfaces can be used to obtain accurate scale drawings. In this example—the Warehouse and Stable of San Miguel del Vado, New Mexico—use of control marks, equidistant camera stations, and overlapping photographs saved the recording team the effort of hand measuring the irregularities of the building and the expense of securing exactly scaled photographic enlargements. With a level, an optical square (a hand-held instrument with two pentagonal prisms), a measuring tape, a tripod and a camera with a targeted circle in the center of the viewfinder, it is relatively simple to establish a series of equidistant control marks at a constant level on a long continuous wall and a series of equidistant camera stations on a line parallel with the wall. At each camera station, located on lines perpendicular to the wall at the control marks, the camera is cranked up on its tripod to the height of the control mark opposite it; the camera axis is then directed perpendicular to the wall by aiming at the control mark with the viewfinder. There should be enough of an overlap in each photograph to record two adjacent control marks, or approximately a 60 percent overlap. It is a simple procedure to use the control marks on the photographs and the same control marks scaled onto the drawings to locate all other points of architectural interest on the wall surface by a method of graphic intersections. Each point on the photograph can be identified by the intersection of lines from two or more control marks. These points are then located on the drawing by the intersection of lines drawn through the control marks on the drawing parallel to the lines drawn on the photograph. The overlapping of photographs makes it possible to view the wall stereoscopically with a pocket stereoscope to identify elements deviating strongly from the plane. With mirror stereoscope and parallax bar, it is possible to calculate the necessary perspective corrections for the orthographic location of projecting elements such as the canales, or drain spouts, in this example from New Mexico. Drawn by Zeno A. Yeates and Joseph J. Bilello for HABS, 1975.

placement, an important consideration in obtaining accurate data, is described in greater detail in Chambers's report mentioned above.) The resulting distorted photographs are then "corrected" in the laboratory, using complex enlarging projectors, called **rectifiers**, which permit the following adjustments:

1. Change of the scale of the enlargement.

2. Change of inclination of the projection table.

3. Change of swing, or rotation of the negative around the axis of projection.

4. Displacement of the negative normal to the tilt axis of the projection table.

5. Displacement of the negative parallel to the tilt axis of the projection table.

It is also customary that the negative plane of the rectifier can be tilted in relation to the lensboard and to the projection table to gain a common line of intersection of these three planes and an overall sharpness of projection. This principle, commonly known as the **Scheimflug condition**, applies automatically to almost all modern rectifiers.

Figure 8: Building in the historic sector of Bordeaux, France, illustrating laboratory rectification of photographs. The upper photograph shows the perspective distortion caused by the necessary tilting of the camera to record the entire facade. The lower photograph has been laboratory rectified with the major plane of the facade in true orthographic proportion. Institut Géographique National, France.

EXAMPLE 3: REVERSE PERSPECTIVE ANALYSIS OF OLD PHOTOGRAPHS: GEOMETRICALLY REGULAR ARCHITECTURAL SUBJECTS

The preceding examples use single photographs to gain orthographic data for a single, essentially plane surface. There are other methods of considerable geometric ingenuity that apply reverse perspective analysis to a single photograph to gain orthographic data for several architectural planes in considerable depth of object space. These methods depend upon three important requirements:

1. The geometric regularity of architectural elements; that is, truly horizontal and vertical architectural surfaces and edges, true circles, rectangular corners, and sets of parallel lines.

2. Several known dimensions to establish scale for a drawing.

3. A dimensionally stable photographic image, as in the case of negatives on photographic glass plates.

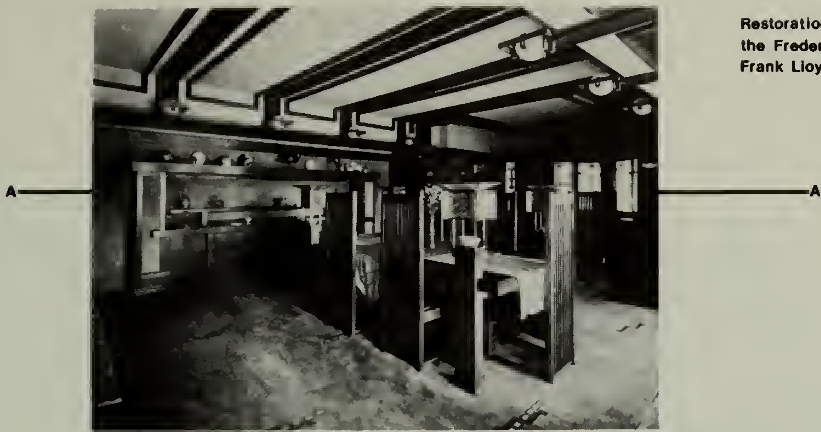
An appropriate application of reverse perspective analysis can be seen in the restoration of the dining room table designed by Frank Lloyd Wright for the Robie House in Chicago (figure 9). The ends of the table and four lighting standards had been cut off this table and were missing; all that remained was the center portion of the table and the accompanying chairs. The sponsors of the project, the Art Institute of Chicago, fortunately had a photograph showing the table as it appeared in 1906 when the house was built. In 1972 the Art Institute contracted for the Ohio State University to prepare accurate drawings of the original table. These drawings were then used by craftsmen to reconstruct the missing portions. Figure 9 illustrates how reverse perspective analysis was used in this case.

It should be noted that this type of reverse perspective analysis cannot be applied to architectural structures that are deformed—the ceiling beams in the Robie House had too much deflection to serve for determining vanishing points and horizon line—nor can it be applied to architecture in which deliberate optical illusions have been created, as in the case of Baroque and Rococo palaces and churches of the 17th and 18th centuries.

EXAMPLE 4: REVERSE PERSPECTIVE ANALYSIS OF OLD PHOTOGRAPHS: GEOMETRICALLY IRREGULAR ARCHITECTURAL SUBJECTS

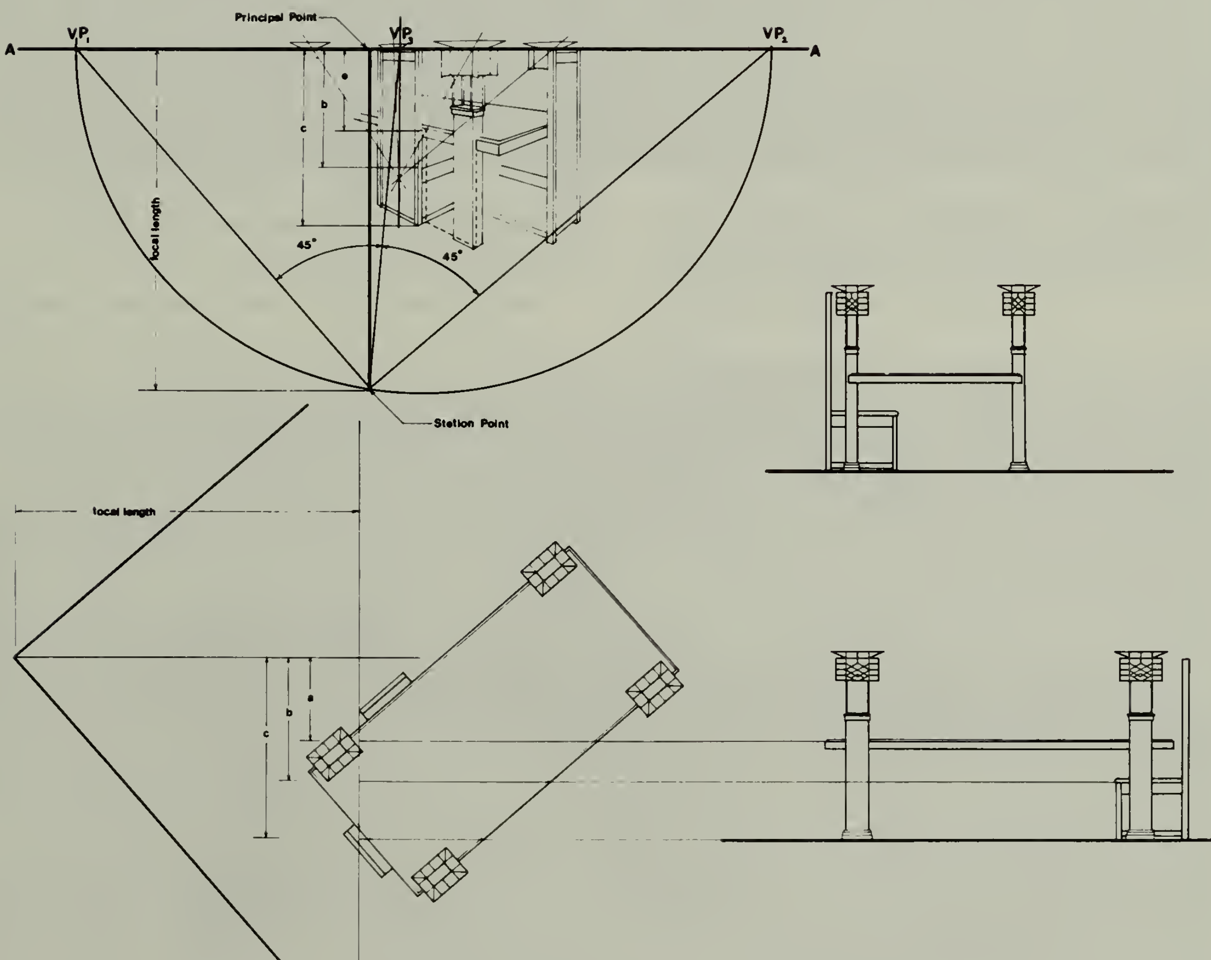
The pueblo of Tesuque, near Santa Fe, New Mexico (figure 12), is an example of historic photographs being used to gain measurable data for irregular structures which have disappeared. The pueblo was photographed from the air in 1973, and photogrammetric drawings of the plan and elevations were prepared. These drawings confirmed that the pueblo had deteriorated greatly from its appearance in historic photographs taken prior to 1900 (found in the Smithsonian archives and other museums). The photogrammetric re-

Figure 9: The photogrammetric system of reverse perspective analysis of old photographs can be used to reconstruct portions of buildings or objects that have been destroyed. In this example, the Art Institute of Chicago was able to restore a dining room table, designed by Frank Lloyd Wright for the Frederick G. Robie residence, Chicago, Illinois, from drawings prepared at the Ohio State University. Dimensions needed for reconstructing missing light standards were obtained first by finding three vanishing points (VP_1, VP_2, and VP_3) on the image plane. VP_1 and VP_2 were found by locating the points of convergence of two systems of parallel lines, at right angles to each other on the table. Those points located the horizon and two vanishing points. VP_3 was located by finding the point of convergence of the sloping mitered lines of the beveled lampshade. From that point a perpendicular was drawn to the horizon. The camera station was then located by finding the point on a semi-circle connecting VP_1 and VP_2 that is the vertex of two 45° angles between VP_1 and VP_2 and VP_3 and VP_2. The principal point in the image plane is located by drawing a perpendicular to the horizon from the camera station previously located. Using the known scale dimensions of the dining room chairs (a, b, and c in the figure), a plan and elevations of the ends of the table could then be drawn. There was confirmation of the accuracy of the results in the discovery of 30° and 45° slopes—sure evidence of the architectural designer—in the ornamental bars across the face of the lighting standards.



Restoration Drawings of the dining room table from the Frederick G. Robie residence by Frank Lloyd Wright (1906).

1. The Camera Station is determined by finding 3 vanishing points on the image plane.
2. VP_1 and VP_2 are found by locating the points of convergence of two systems of parallel lines, at right angles to each other on the table. Those points locate the Horizon and two Vanishing Points.
3. VP_3 is located by finding the point of convergence of the sloping mitered lines of the light standards. From that point a perpendicular is drawn to the horizon, locating the vanishing point of lines bisecting the right angles of the first two systems of parallel lines.
4. The Station Point is located by finding the point on a semi-circle connecting VP_1 and VP_2, that is the vertex of two 45° angles between VP_1 & VP_3 and VP_3 & VP_2. The Principal Point in the image plane is located by drawing a perpendicular to the horizon.



cordings of 1973 were used to provide geometric control for determining camera orientation of the historic photographs, and those in turn, provide an accurate basis for reconstruction work.

Twelve building corners (P_1–P_{12} on figure 10) in the 1973 plan of Tesuque were considered constant in location and recognizable in several historic photographs of the pueblo taken in 1879 and 1899. Continuity in the ground plan of Indian pueblos over a long period of time could be assumed, first, because of clan ownership of house groups; second, because of the importance of the dance plazas upon which there should be no encroachment by new construction; and third; because of the more permanent stone foundations placed under adobe walls to prevent their collapse from capillary moisture rising into the wall from the ground. When pueblo walls do collapse, they tend to be raised again upon these original stone foundations.

Figure 10 is a graphic analysis of the "fit" of six historic photographs to the plan of the pueblo to Tesuque, showing camera station points, camera axes, and image planes, all drawn in positive image position. For this analysis, it was essential first to determine the location of camera stations by any and every possible **fix** on the foreground and background points of the pueblo or of the hills beyond. A **fix** is a line of sight joining background object, foreground object and the camera station in one continuous line on the plan of the pueblo. A comparison of photographs (figure 11) provides a good example of determining a **fix.**

Figure 10: Reverse perspective analysis of historic photographs of the Pueblo of Tesuque, New Mexico, shown upon a reconstructed plan of the pueblo as it appeared in 1899. Historic photographs by John Hillers and Adam Clark Vroman (S_1—S_5) were analyzed to determine their camera stations, camera axes and image planes. Then the intersection of corresponding lines of sight from two or more camera stations to architectural elements in the pueblo located and dimensioned those elements for the reconstruction drawings. Prepared for HABS at the Ohio State University, 1974, with reverse perspective analysis by Perry E. Borchers, computer program assistance by Peter Lick-Hong Leung, and delineation by Julsing J. Lamsam.

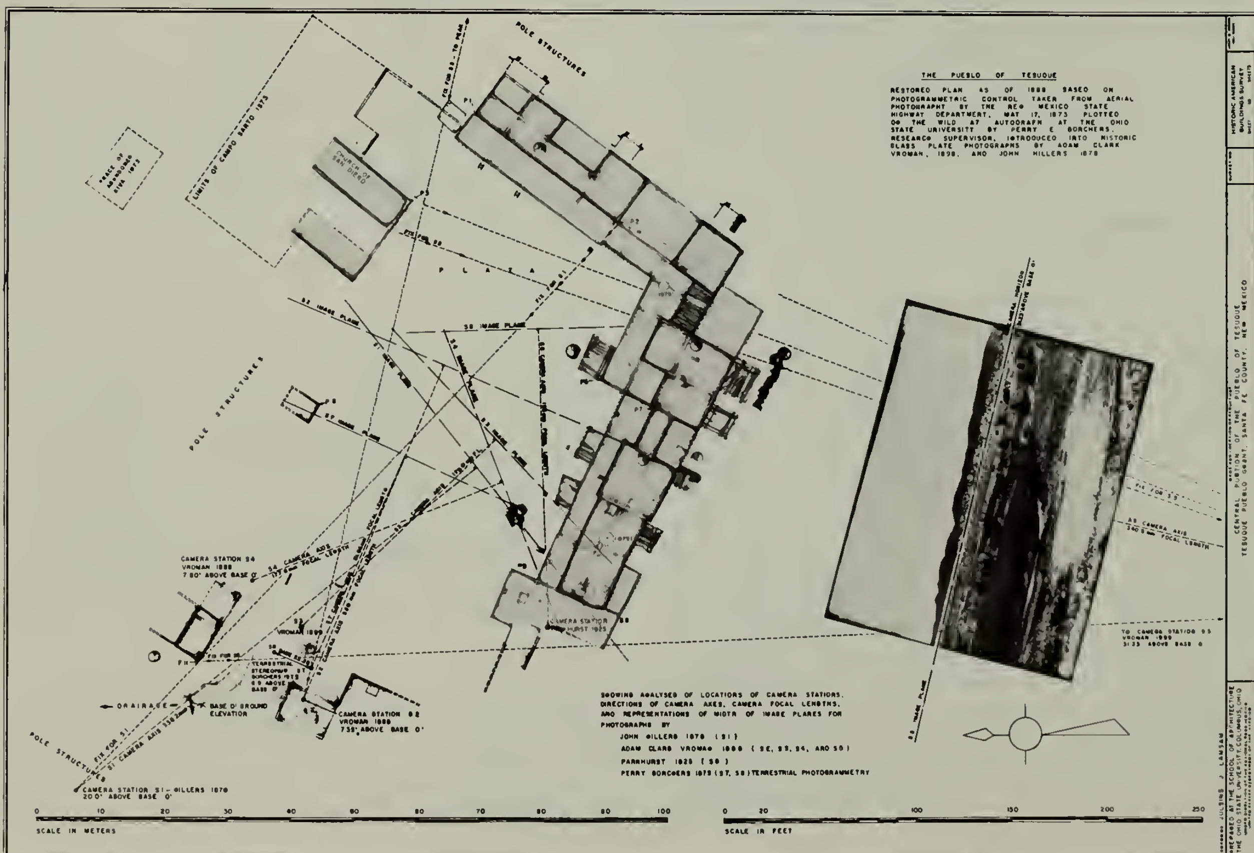


Figure 11: The upper photograph is a historic view of the Pueblo of Tesuque taken by Adam Clark Vroman in 1899 (camera station S_2 in figure 10). Compare this photograph with the one taken in 1973 (actually part of a terrestrial stereopair) to reproduce as nearly as possible the same camera station as the photograph of 1899. (Camera station S_7 in Figure 10). Note the fix on the distant hilltops seen between the church front and the end of the second story of the pueblo in both views.

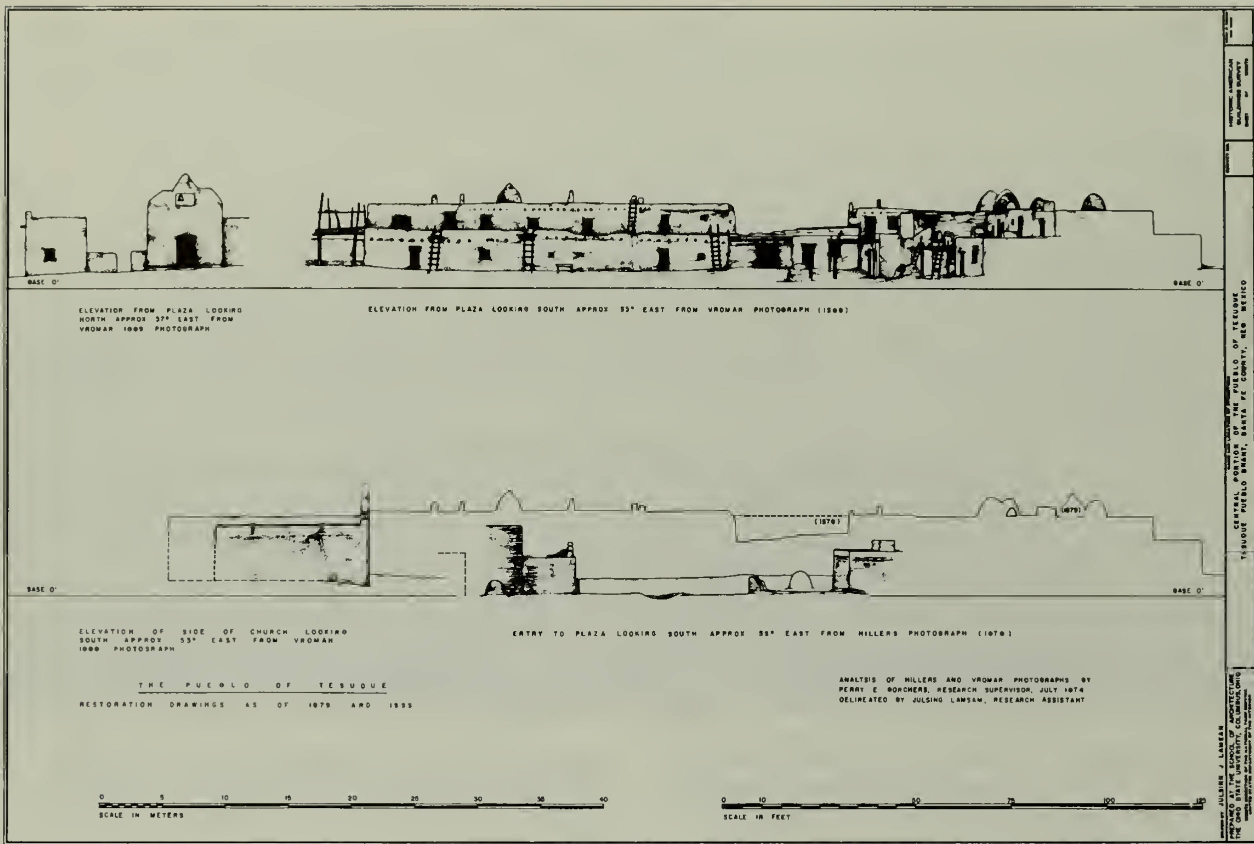


Figure 12: Central portion of the Pueblo of Tesuque, New Mexico, as it existed in 1899. Prepared for HABS at the Ohio State University, 1974, with reverse perspective analysis by Perry E. Borchers, computer program assistance by Peter Lick-Hong Leung, and delineation by Julsing J. Lamsam.

When the camera stations had been fairly closely determined, lines of sight were drawn in plan from the camera stations to the selected control points (P_1–P_{12}) in the pueblo. The horizontal dimensions of the photographs were fitted to the lines of sight drawn in plan to determine the location of the image planes. A line drawn from the camera station perpendicular to the image plane determined the direction of the camera axis and the principal point of the image plane. The measurement of this line indicated the focal length of the camera at the time of photography.

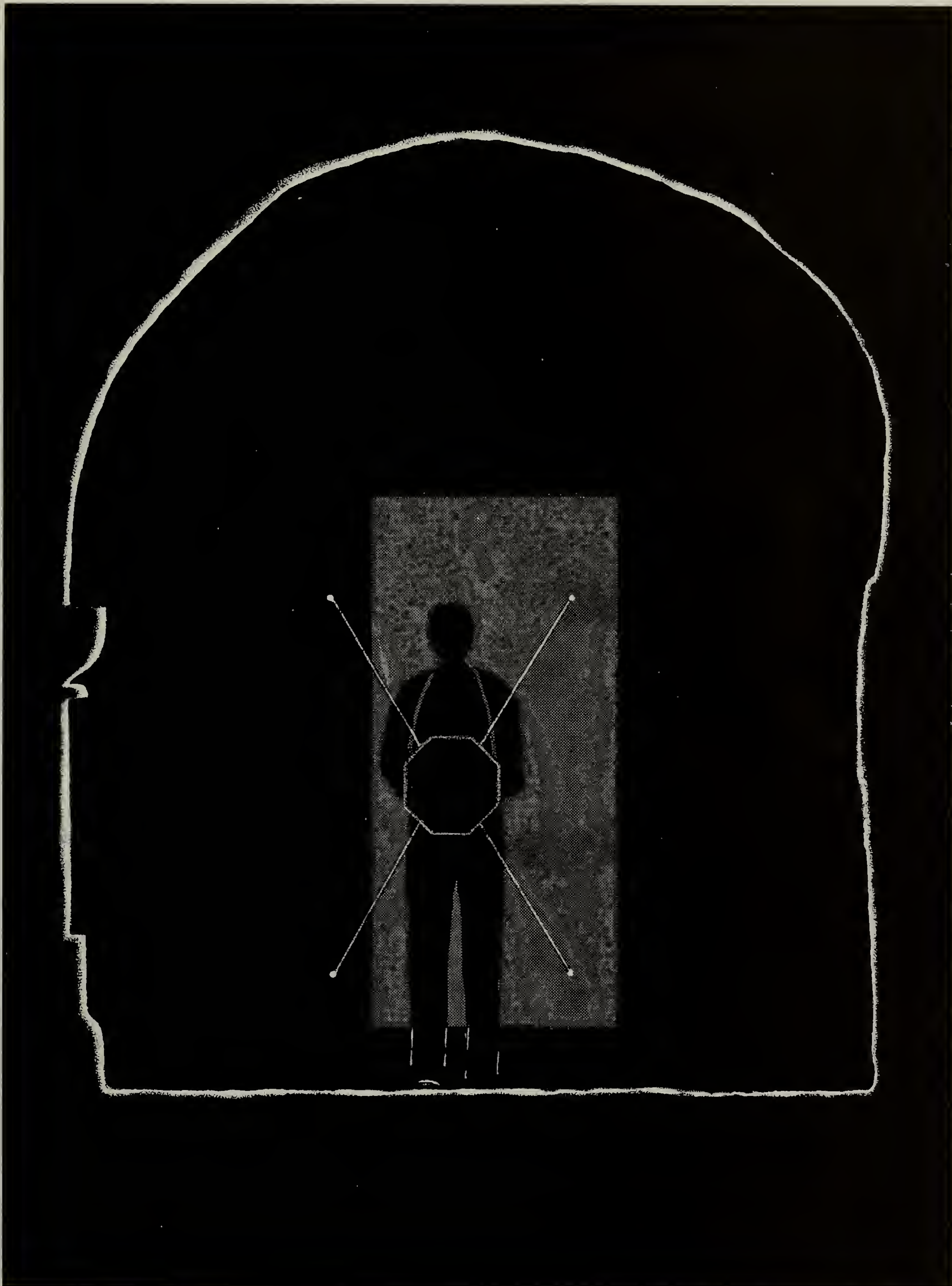
Then it was only necessary to project other lines of sight through the photographs to determine the location of points that had not been used in the adjustment procedure and to draw structures that had disappeared since the photographs of 1879 and 1899. Figure 12 shows drawings of the plaza elevations of Tesuque as they existed prior to 1900, based on this procedure. These drawings may be used in restoration of the pueblo.

EXAMPLE 5: RECORDING TUNNELS AND PASSAGEWAYS BY THE METHOD OF "LUMINOUS SECTIONS"

An unusual variant of single-picture photogrammetry is the method of "luminous sections," which has been successfully used in Czechoslovakia for recording and drawing underground or dark passageways in caverns, mines, and architectural monuments.

This ingenious method of photogrammetric recording of narrow and irregular spaces is illustrated in figure 13. It employs a special apparatus consisting of two parallel shields between which

Figure 13: The method of luminous sections applied to the drawing of underground passages. Illustration shows apparatus used to record surfaces. Drawn by Kun-hyuck Ahn, based on photograph from the Institute of Ore Research, Prague, 1971. Courtesy: M. Jirinec



is a source of light. Four prongs of known dimension project outwards from the space between the shields.

With a **phototheodolite,** a camera designed to read horizontal and vertical angles, set up on a known camera axis and with the camera lens opened in relative or absolute darkness, the luminous section of floor, walls, and ceiling surrounding the man carrying the apparatus is exposed by a flash of light which the shields confine nearly to a plane. The four prongs of the apparatus, also exposed and recorded on the photographic plate by the plane of light, provide survey control for the calculation of distance and the discovery of any angling of the apparatus in relation to the camera station and the camera axis of the phototheodolite.

EXAMPLE 6: STEREOPHOTOGRAMMETRY

Because of its flexibility in both the recording and plotting of survey data, stereophotogrammetry has become the most frequently employed method in architectural photogrammetry. It is equally adaptable to aerial photography and to terrestrial photogrammetry of historic structures.

Basic Principles

Unlike photogrammetric methods using single photographs, stereophotogrammetry is dependent upon binocular vision (figure 14). Stereophotogrammetry uses pairs of photographic images (or stereopairs) taken from two camera stations displaced from each other to duplicate and exaggerate the normal horizontal parallaxes of binocular vision.

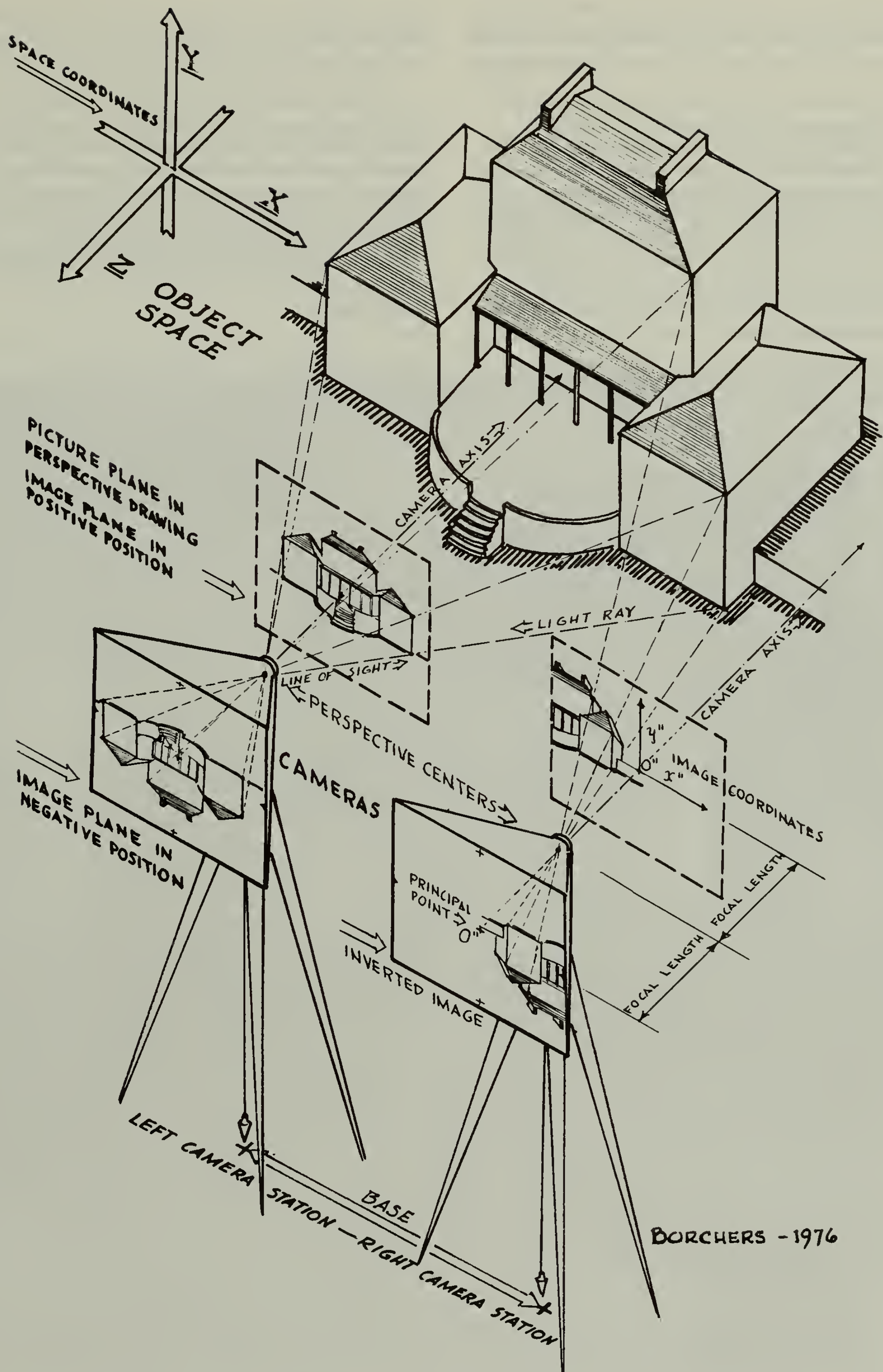
Using the setup illustrated in figure 15, two consecutive photographic images are taken of the object. If these images are later inserted into an appropriate viewing instrument, which makes it possible for the left-hand photo to be seen by the left eye and the right-hand photo to be seen by the right eye, the observer will perceive a three-dimensional model of the object photographed. This is worth repeating: in stereoscopic viewing of one image in each eye, the two images fuse into a single "optical model" of the object in object space. It should be recognized that in many cases, such as when native craftsmen are employed in the partial dismantling, stabilization and rebuilding of historic walls, that the stereopair itself provides the best possible information for restoration work, free of the confusion that architectural drawings may have for those who are not thoroughly acquainted with them.

Recording Equipment and Photographic Coverage

In stereophotogrammetry two photographs of an object are taken, recording two overlapping images differing in horizontal parallaxes. The cameras used to take these photographs are generally of two types: 1) photogrammetric stereocamera, or 2) phototheodolites. A photogrammetric stereocamera is actually two wide angle cameras mounted on an adjustable bar. Photogrammetric stereocameras take **simultaneous photographs** with parallel camera axes and with a base distance between cameras varying from 40 cm. to 3 m. Phototheodolites, on the other hand are precise cameras mounted upon surveying instruments for the taking of **successive photographs** from widely separated camera stations (see figure 15). The maximum depth of reasonably accurate plotting is 20 times the base distance between the two camera stations, but a greater base/distance ratio increases the accuracy of plotting and measurement. It is desirable to maintain the same scale in both photographic images by

Figure 14: Stereophotogrammetric procedure and terms. Light rays from a real object pass through the perspective center of a camera lens, striking the image plane in the negative position. In perspective drawing, or in positive photographic prints, lines of sight from the eye to the object penetrate a picture plane in positive position between the eye and the object.

To produce the pairs of photographic images required for stereophotogrammetry, two camera stations are established, with a horizontal displacement between them, with essentially parallel camera axes (vertical in aerial photography and either horizontal or inclined in terrestrial photography). As illustrated here, the base between the two camera stations is essentially perpendicular to the camera axes. In aerial photography, the movement of the airplane provides the base between new stations for each successive frame. In terrestrial photography, a rigid base separating two stereometric cameras causes the displacement, or a phototheodolite, set up at two successive camera stations, may also be used.


SPACE COORDINATES
Y
X
Z
OBJECT SPACE
PICTURE PLANE IN PERSPECTIVE DRAWING
IMAGE PLANE IN POSITIVE POSITION
CAMERA AXIS
LIGHT RAY
LINE OF SIGHT
PERSPECTIVE CENTERS
CAMERA AXIS
y"
0"
x"
IMAGE COORDINATES
CAMERAS
IMAGE PLANE IN NEGATIVE POSITION
PRINCIPAL POINT
0"
INVERTED IMAGE
FOCAL LENGTH
FOCAL LENGTH
LEFT CAMERA STATION
BASE
RIGHT CAMERA STATION
BORCHERS - 1976

photographing on parallel camera axes with the base between camera stations perpendicular to the camera axes. This is done by setting up two tripods on which are mounted alternately the phototheodolite and a target. The theodolite serves to turn precise orientation angles, to level the

Figure 15: Setup of a Galileo-Santoni phototheodolite for stereophotogrammetric recording of a Greek sculpture in the Cleveland Museum of Art, 1966.

In this situation, the two camera stations have already been established where the tripods are set up; the telescope of the phototheodolite on the right tripod has previously been sighted at the target on the left tripod. A 90° angle has then been turned towards the subject. After a photograph is taken from the right tripod, the equipment is interchanged and a photograph is taken from the left tripod.

Carefully measured survey control is marked by taped crosses near the subject at the horizon of the right camera. The other equipment near the statue includes a shadow-line frame and a parallel light projector to cast contours on the statue for monocular plotting where stereoscopic vision is blocked at the extreme profiles in orthographic projection. A companion drawing to that in figure 2 was prepared of this kouros at the Ohio State University for Dr. Ilse Kleeman.

camera mounted upon it, and to duplicate any necessary upward inclination of the camera axis. It is also used to establish control points within the object space at the horizon of the camera.

The camera that is set upon the theodolite is a rigid box with a lens of known focal length and negligible distortion. It has been precisely calibrated, and a residual lens distortion curve has been prepared for it under conditions of actual use.

Flat glass photographic plates of large format are used to secure good detail in the negative, and to avoid film shrinkage and distortion that occurs with films and paper. Within the camera, the photographic plate is drawn tightly against four pressure points at the moment of exposure, and four fiducial marks record the location of the camera axis, rigidly fixed within a box which has no rising, sliding, or tilting lensboard, or swing-back. [1]

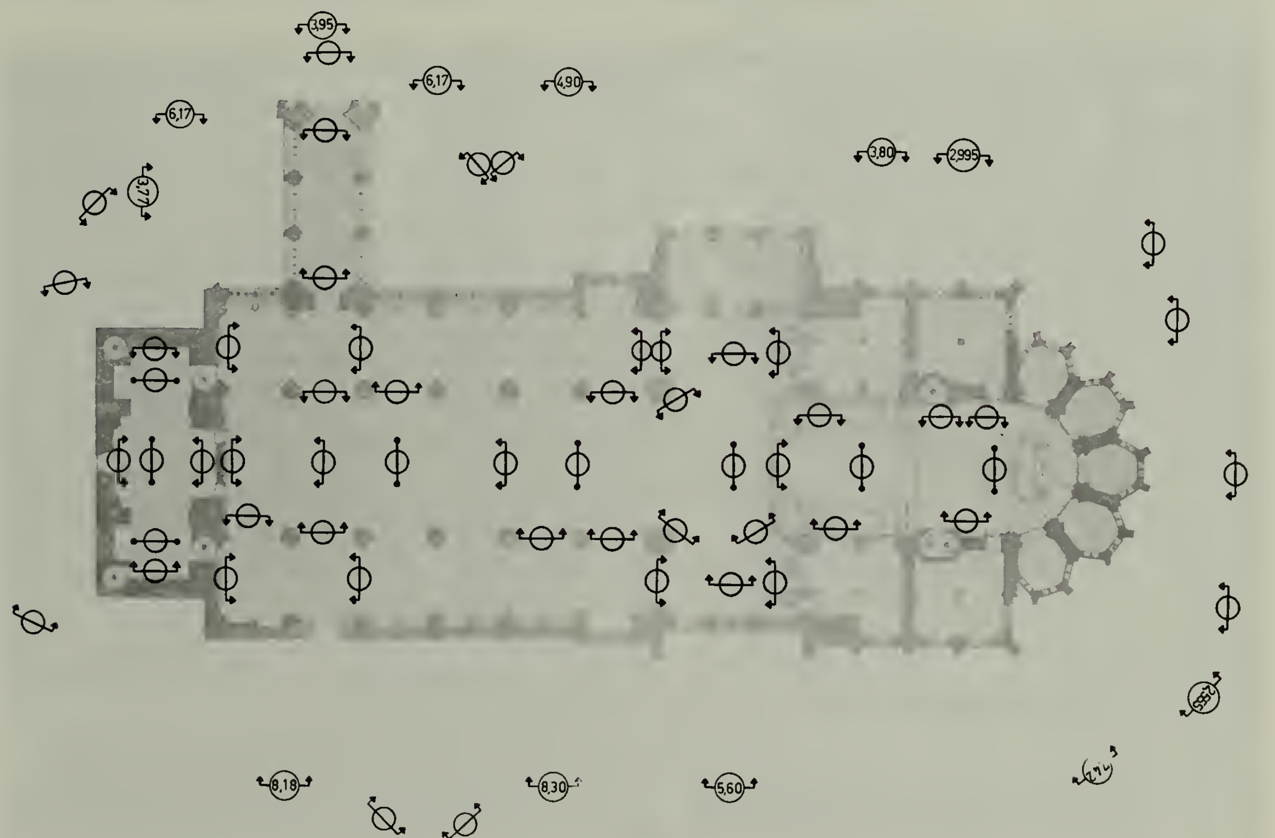
Figure 15 shows the setup for stereophotogrammetric recording in 1966, of an archaic Greek statue, in the Cleveland Museum of Art, with a phototheodolite and target arranged upon two tripods.

The two camera stations are marked by the tripods. The telescope of the phototheodolite on the right has previously been sighted at the target

[1] This information also appears in Perry Borchers, "Architectural Photogrammetry in Restoration," *Building Research* (vol. 1, no. 5, 1964).

Figure 16: Plan for the comprehensive stereophotogrammetric recording of l'Eglise Saint-Jacques, Belgium, by the Royal Ministry of Public Works, prior to 1956.

Horizontal and vertical photography with fixed base stereocameras make up most of the photography. Vertical photography is concentrated along the nave, while the direction of horizontal photography is indicated by arrows through the circles. Photography at great distances, requiring wide bases between camera stations, is indicated by the circled distances in meters.



on the left tripod and a 90° angle has then been turned towards the subject. After photography from the right camera station, the phototheodolite and the target will be interchanged on the two tripods; another right angle will be turned from target to subject; and the left photograph of the stereopair will be taken on a camera axis parallel to that of the right photograph. The camera of the phototheodolite has a precise inner orientation recorded on the photographic plate. This camera is somewhat unusual in that the focal length can be increased by precise increments to allow the close-up photography seen in this example.

Not all recording set-ups are as simple as the one just described. In architectural photogrammetry, ingenuity is more often required at the site than at the plotting instrument or drawing board. A major problem is to gain photographic coverage. Only that which appears upon a photograph—more often, only that which appears upon two photographs of a stereopair—can be photogrammetrically measured and drawn.

Figure 16 diagrams the comprehensive stereophotogrammetric recording of the Gothic church of Saint Jacques as carried out by the photogrammetric section of the Ministry of Public Works of the Kingdom of Belgium prior to 1956. Most of the horizontal and vertical photography was done with fixed base stereocameras. Photography of the more distant features required wide bases between camera stations (to increase the accuracy of the plotting) as indicated by the circled distances in meters.

Sometimes photography must be precisely scheduled, as in the case of the stereopair of the east facade of Trinity Church on lower Broadway in New York City—shown in figure 17—as photo-

Figure 17: Left photograph of a stereopair of the east facade of Trinity Church down length of Wall Street, New York City.
. . Some architectural subjects can be extremely difficult to record photogrammetrically. Located at the end of a busy street lined by tall buildings, the coal black facade of Trinity Church is sunlit for only a few minutes each day. This stereopair was taken one Sunday morning when Wall Street was deserted. The Ohio State University 1959, for the Corporation of Trinity Church, New York City.

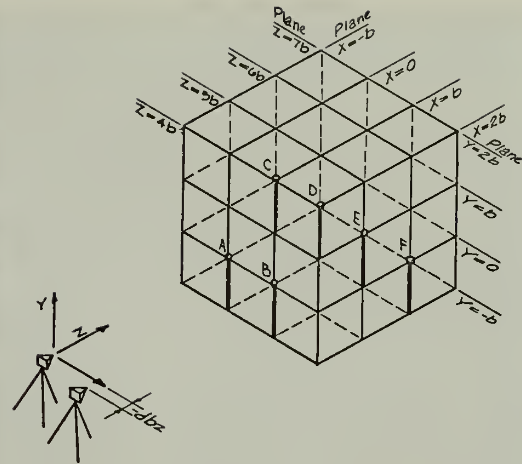


Figure 18: A typical arrangement of six survey poles (A-F) as "survey control" is shown during the photogrammetric recording of the Pavilion Hotel, Montpelier, Vermont. An isometric diagram of this "survey control" shows the planes examined for distortion and the position of the cameras in relation to the survey poles. The Ohio State University, 1969.

graphed during a few minutes of Sunday morning sunlight down the length of Wall Street in September 1959. At any other time of day, the coal-black facade of Trinity Church would have been in shadow. On any other day of the week, traffic conditions would have been intolerable.

Survey Control for Stereophotogrammetry—Together with the photographic stereopair, "survey control" notes make up the basic photogrammetric record; for this reason, it is important to plan this phase of recording carefully. A few measurements within the picture area, together with the control points recorded upon the camera horizon, provide survey control for orienting the plates within the plotting machine, establishing scale, and determining accuracy through calculation of a standard error. A more detailed discussion, entitled, "Choice of Station and Control for Efficient Orientation and Plotting in Architectural Photogrammetry," appeared in *Photogrammetric Engineering*, December 1960.

A typical arrangement of six surveyor's poles as "survey control" for architectural photogrammetry is shown in figure 18. The poles are marked with tape at the camera horizon, and the measurements between all the marks are recorded as survey control data.

Another form of "survey control" is seen in the suspended measuring tapes across the dome of the rotunda of the Old Statehouse in Annapolis, Maryland, as shown in figure 19. This was control for vertical photography from the floor of the rotunda up into a tall and slender drum and dome.

Errors in Measurement—There are three types of errors that can occur in any system of measurement:

1. Blunders. These are often due to errors in recording data and can be readily identified and eliminated in photogrammetric procedure.

2. Systematic errors. These can occur because of some uncorrected element of orientation, such as the tilt of one camera axis, which can be identified and eliminated by analysis of residual discrepancies in the survey control measured in the optical model. Figure 20 illustrates systematic errors in a series of planes similar to architectural surfaces in their locations.

3. Random errors. These are often due to the limit of resolution of a photographic emulsion or due to lack of flatness of photogrammetric plates. Random errors make up the most common type of error in photogrammetric measurement. Accuracy can be improved, however, by discovering a systematic error in what had previously been considered a random error.

When the lack of flatness of photogrammetric

Figure 19: Two measuring tapes were suspended across the dome of the rotunda of the Old Statehouse in Annapolis, and one measuring tape was hung vertically to provide survey control seen in this photograph, which is the left half of a stereopair. Orientation and scale could then be established in the plotting instrument. Perry and Myra Borchers 1970, for the State of Maryland.

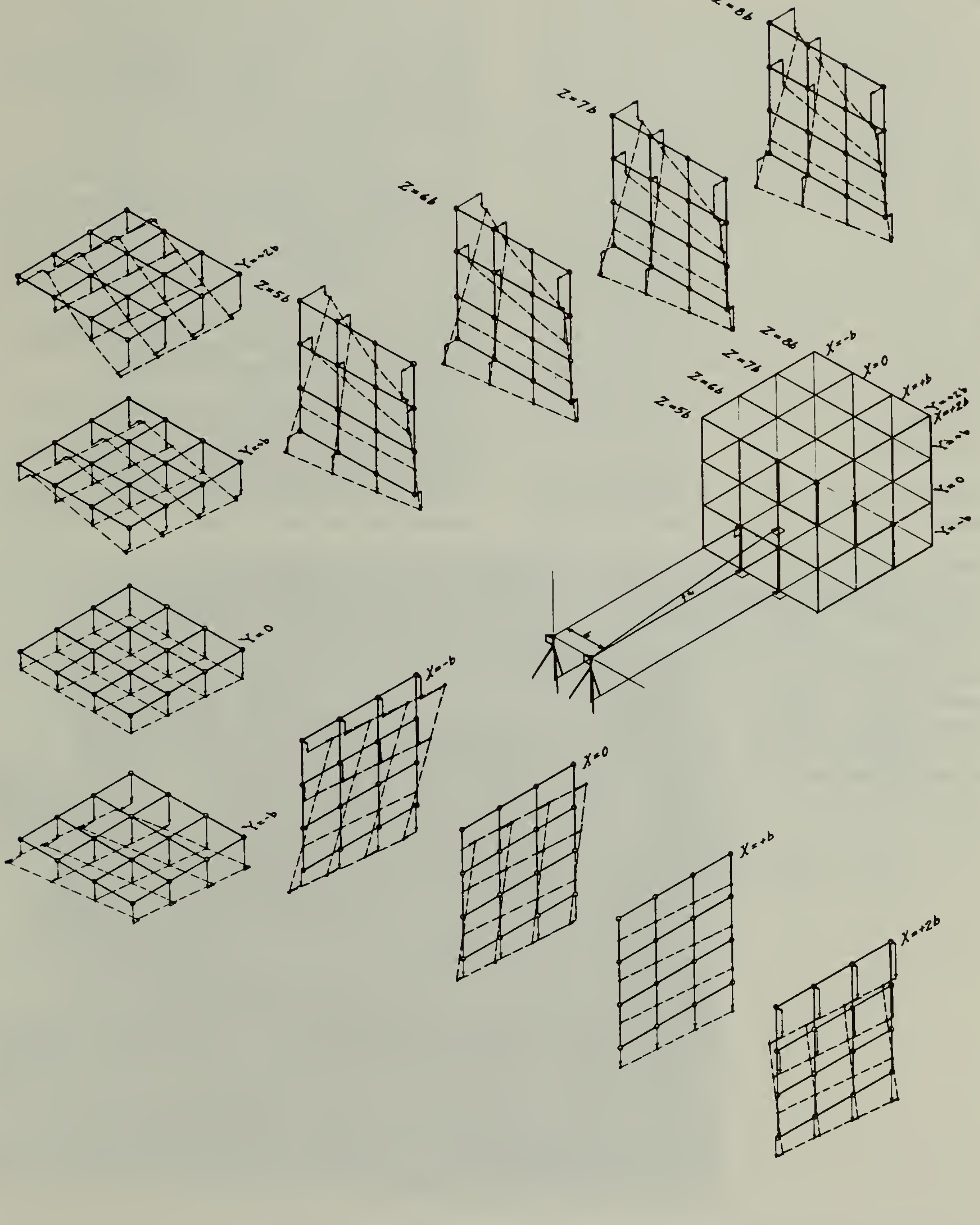
plates can be identified and eliminated from photogrammetric measurements by special procedures and lengthy adjustment computations, it is possible to measure even the movement of buildings due to thermal changes in an interval of time.

Stereophotogrammetric Plotting Equipment and Techniques

After the glass-plate stereopairs have been developed, the optical model they contain is viewed, oriented, measured, and drawn in a complex plotting instrument, such as the Wild A7 Autograph shown in figure 21. A primary operation in such an instrument is to re-establish the relative orientation between the two camera positions at the time of photography. The principal points of the two plates are centered on the plate-holders; the focal length of the camera is reproduced in the instrument; the three space coordinates of the base between camera stations are reproduced to scale; and the azimuth angles (convergence or divergence), the tilts of the two camera axes, and the rotation of the plates around the two camera axes are reproduced to greater accuracy than could be determined in the phototheodolite.

The coherent "optical model" formed by the relative orientation of one photographic plate to the other, as described above, is then rotated into absolute orientation to the coordinate system of object space. The model is properly scaled, the survey control in the optical model is made to agree closely with the scaled dimensions of the survey control previously measured in object space, with the residual discrepancies being the basis for computing the standard error of the model. After these adjustments, measurement and drawing can start.

Figure 20: Distortion of a series of planes in the "optical model"—in positions similar to architectural surfaces—due to an uncorrected tilt of one camera axis. This is an example of systematic error.



Within the instrument, two dots—one in the center of each eyepiece—can be made to coincide into a single measuring mark. This having been moved in depth to touch a point on the "optical model," eliminates the effect of perspective at that point, and records and draws—with the drop of a pencil on the plotting table—the orthographic coordinates of the point it touches or the edge along which it moves. Two handwheels and a foot treadle move the measuring mark in the three coordinate directions in space. This controlled movement over and around the fully oriented optical model is like movement over the building itself. It is the most impressive part of the photogrammetric procedure. The discoveries can be surprising. Architects, rather than photogrammetric technicians, should be trained to use the plotting instrument in architectural photogrammetry. In traveling visually over the surface of the optical model while drawing it completely to scale, architects may learn more about the geometry of a building than they could learn in any other way.

Topographic Drawing of Architectural Elements—With the plotting instrument it is possible to draw in two ways, as seen in figure 22, which shows the planimetric drawing and the topographic drawing of French Romanesque ceiling vaults.

The usual architectural drawing is **planimetric**, following the edges of architectural elements. In figure 22, the planimetric drawing follows the stone jointing of the vaults, though the measuring mark must move in depth simultaneously as it moves in length and breadth.

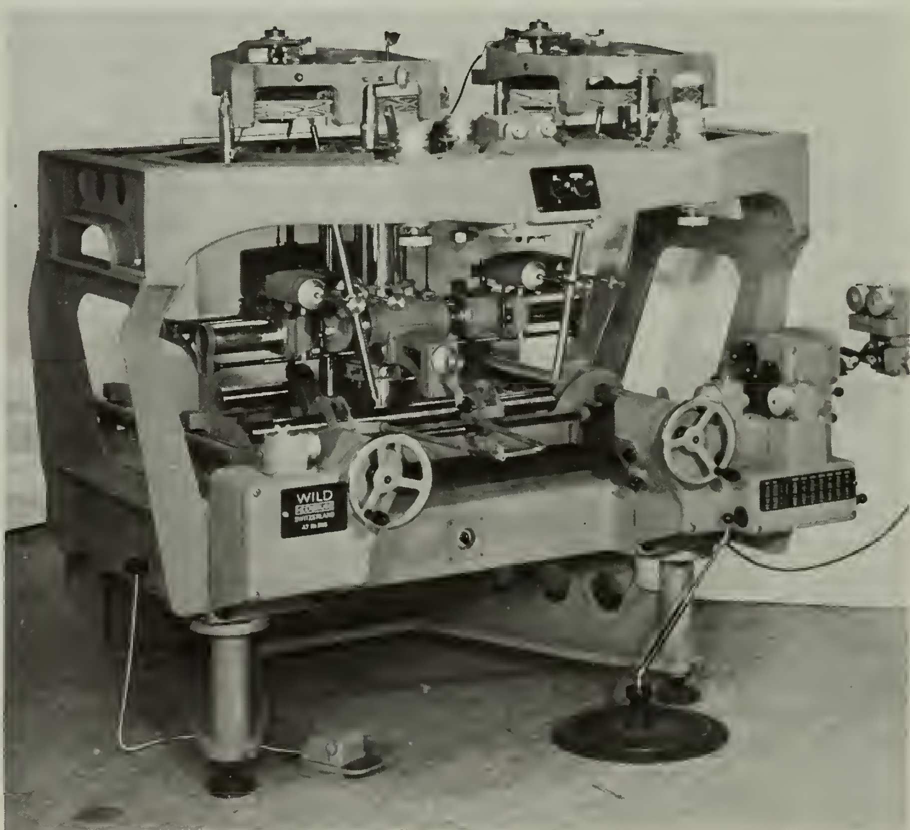
Topographic drawing consists of contours of equal depth, the measuring mark being set at successive increments of depth to draw contours where it touches and travels across a surface. In general, architects do not appreciate how effective

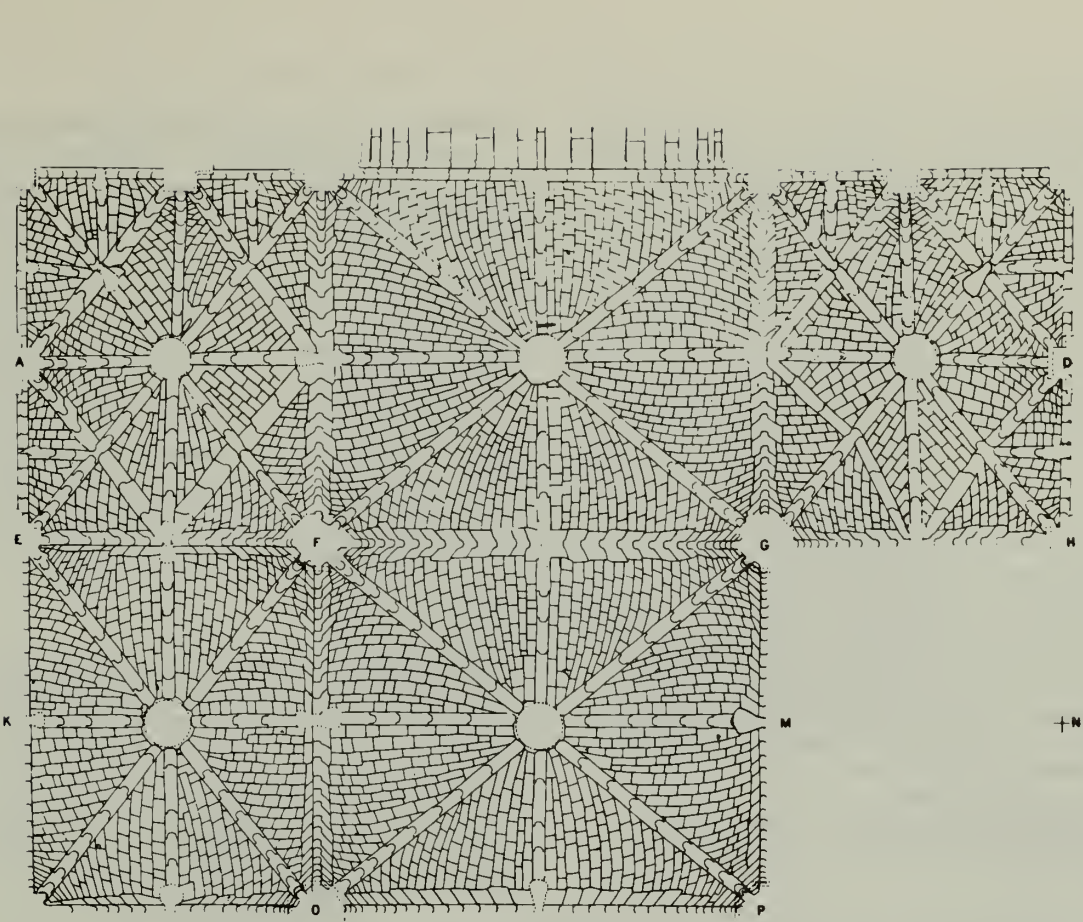
Figure 22. Planimetric and topographic drawings of the Romanesque ceiling vaulting of St. Serge d'Angers, by A. Schlumberger, Société Française de Stéréotopographie.

Planimetric drawing (a) is most commonly used in photogrammetric documentation as it delineates architectural elements—in this case the stone jointing of the vaults. Topographic drawing (b) records the contours of the surface and might indicate, for example, structural problems such as sagging of the vaulting.

Figure 21: The Wild A7 Autograph, universal plotting instrument, at the Ohio State University.

Two handwheels and a foot treadle move the measuring mark in the three coordinate directions in space. A second foot control drops the pencil traveling over the plotting table at lower right.

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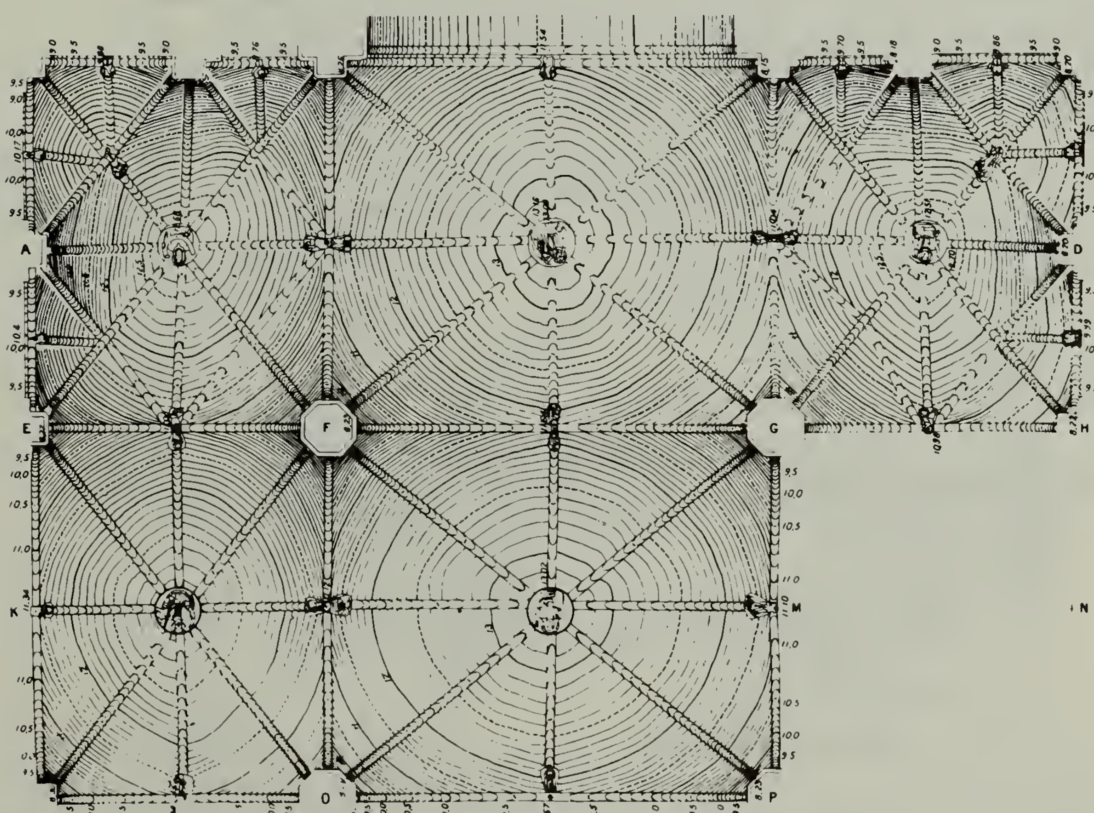
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the combination of planimetric and topographic drawing can be for recording and explaining any deformed or sculptural form in architecture.

Contours can also be drawn as vertical slices at constant increments of depth as seen in figure 23. Vertical contouring can express ground form in relation to architectural facades, or, in sculptural buildings such as massive adobe churches in the American Southwest, can help express architectural form also.

Figure 23: Elevation of Mummy Cave, Canyon de Chelly National Monument, Arizona.

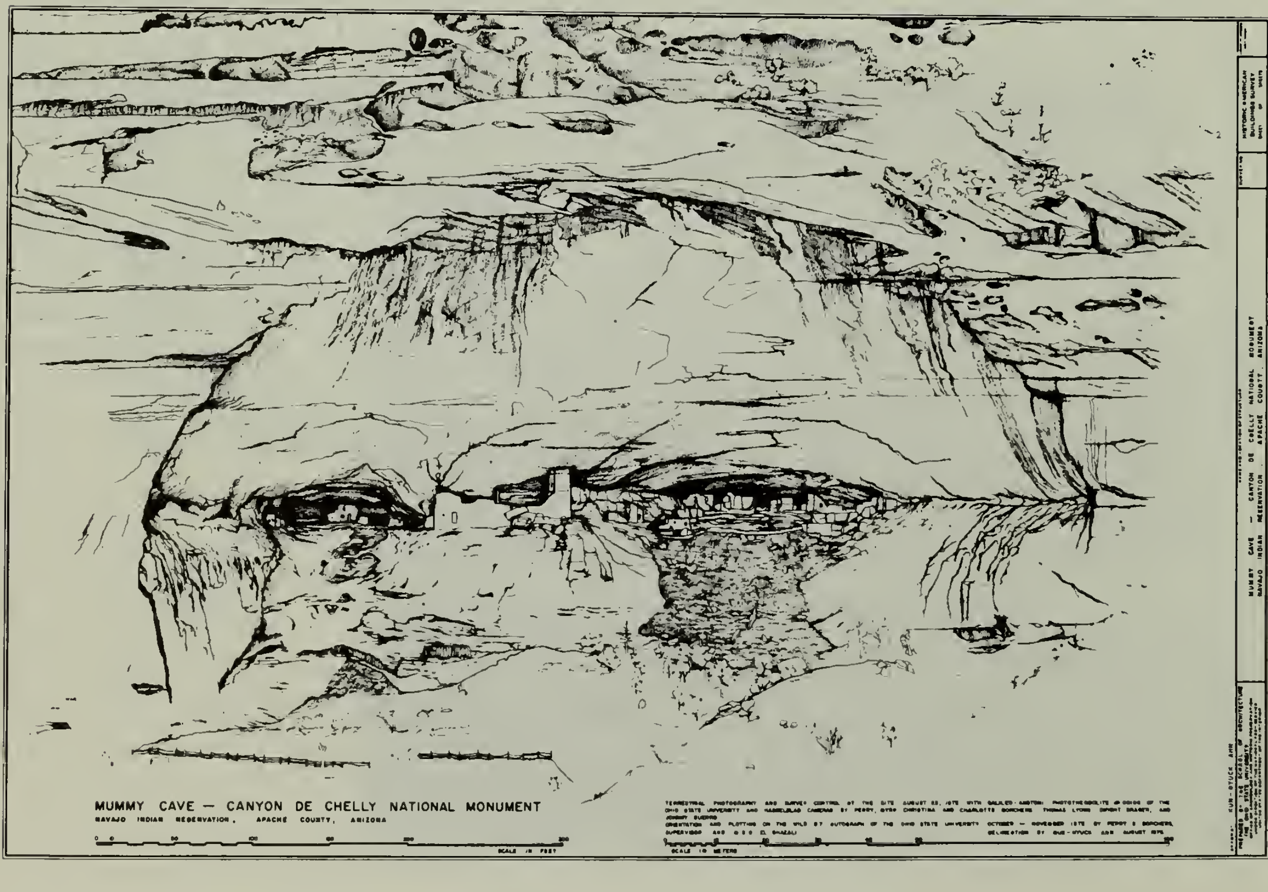
Photogrammetric plotting allows planimetric drawing of the architectural form of this prehistoric dwelling and topographic drawing of the natural cliff setting.

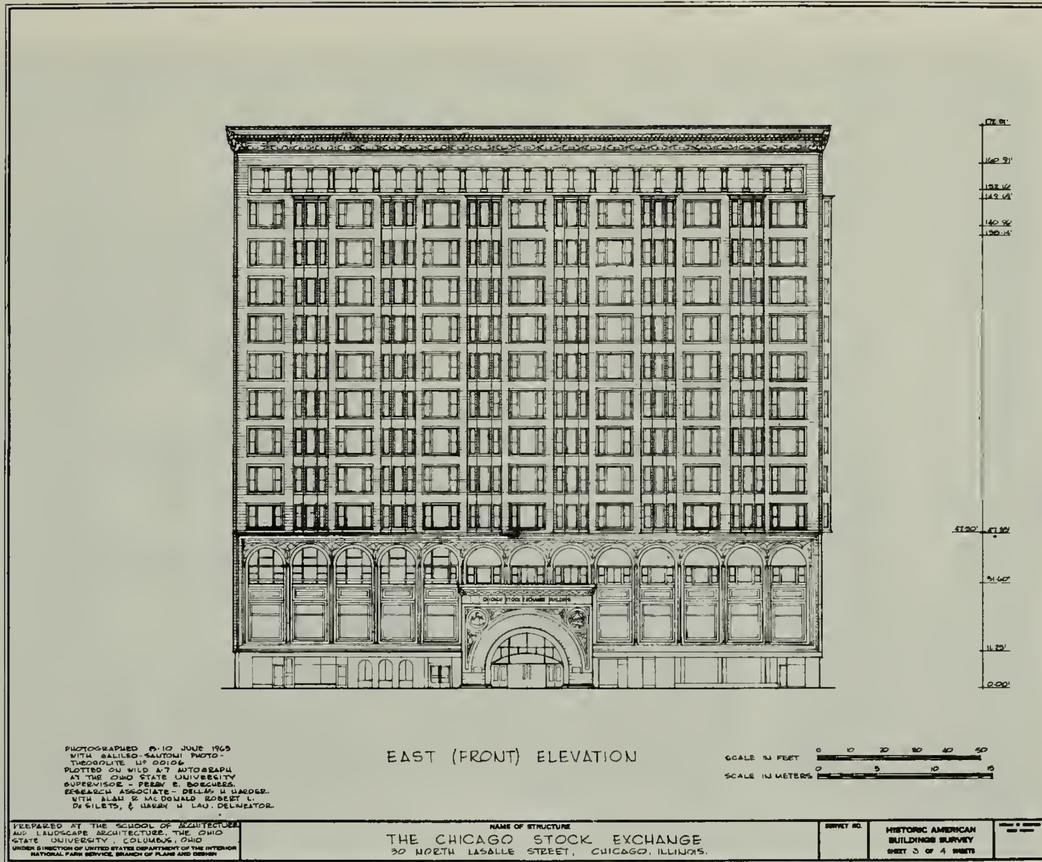
We are accustomed to reading horizontal contour lines on plans or maps, but in this instance the contour lines represent equally spaced vertical slices through the cliff overhanging and through the talus slopes and projecting rock base below.

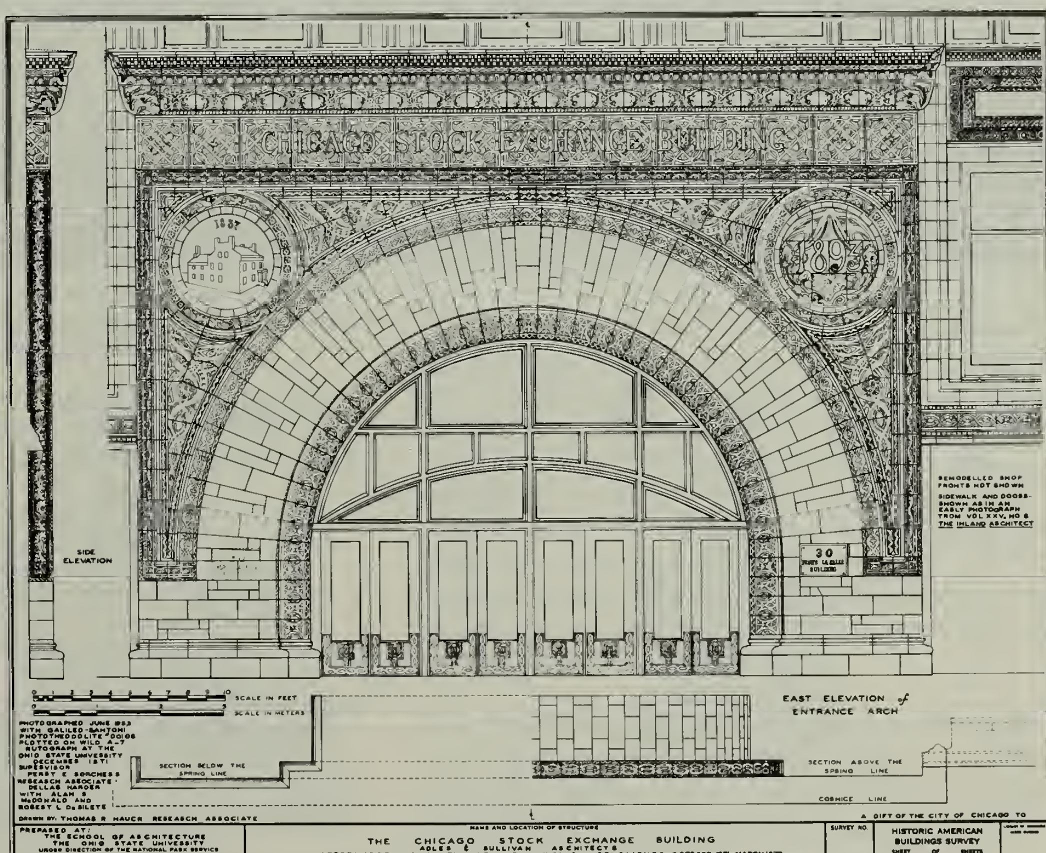
Delineated by Kun-Hyuck Ahn at the Ohio State University, 1976, for Chaco Center, National Park Service.

Change of Scale with Stereophotogrammetry —Another advantage of a plotting instrument such as the Wild A7 Autograph is the ability to change the scale of the drawing by as much as 24 times by change of gears alone. However, when making a small-scale, complete elevation drawing, such as figure 24, the east elevation of the Old Stock Exchange Building in Chicago, it can be frustrating to try to choose significant architectural lines when the measuring mark is traveling over detail as elaborate as that in figure 24A, a large-scale drawing of the entrance archway in the same elevation of the Stock Exchange. The second drawing was made 8 years after the

Figures 24 and 24A: These two drawings of the Chicago Stock Exchange Building, Chicago, Illinois, were prepared from the same stereopair negatives. By adjusting the gears on the plotting machine, the delineator can change the scale of the drawing as needed. In this case, the drawing of the entrance arch was made eight years after the east elevation shown above. Prepared at the Ohio State University for HABS, 1963 and 1971.




EAST (FRONT) ELEVATION
SCALE IN FEET
SCALE IN METERS
NAME OF STRUCTURE
THE CHICAGO STOCK EXCHANGE
30 NORTH LASALLE STREET, CHICAGO, ILLINOIS.
SURVEY NO.
HISTORIC AMERICAN
BUILDINGS SURVEY
SHEET 3 OF 4 SHEETS


CHICAGO STOCK EXCHANGE BUILDING
SIDE ELEVATION
30
SCALE IN FEET
SCALE IN METERS
EAST ELEVATION of
ENTRANCE ARCH
SECTION BELOW THE
SPRING LINE
SECTION ABOVE THE
SPRING LINE
CORNICE LINE
DRAWN BY: THOMAS R HAUCK RESEARCH ASSOCIATE
A GIFT OF THE CITY OF CHICAGO TO
NAME AND LOCATION OF STRUCTURE
THE CHICAGO STOCK EXCHANGE BUILDING
ADLER & SULLIVAN ARCHITECTS
SURVEY NO.
HISTORIC AMERICAN
BUILDINGS SURVEY
SHEET OF SHEETS

ENLARGEMENT OF PHOTOGRAPHIC CENTRAL PROJECTION UPON A VERTICAL IMAGE PLANE

ORTHOGRAPHIC PROJECTION UPON A PLANE INCLINED 25° FROM THE VERTICAL

first drawing from one of the same stereopairs, to serve as the basis for the reassembly of the salvaged archway after demolition of the building.

Orthographic Projection of Details on Curved Surfaces—It is also possible to tilt the coordinate systems of the photogrammetric plotting machine to special advantage. Figure 25 is the right photograph of a stereopair taken in the monastery church of Ossios Loukas near Delphi, Greece, with a Hasselblad Superwide camera. Figures 26 and 26A compare two drawings of the mosaic representation of the Madonna and Child in the apse above the altar of this church.

The left drawing reproduces the camera perspective of the Madonna, far to the upper edge of a wide-angle photograph, where features such as spheres are regularly distorted. The Madonna lies partly on a vertical cylindrical surface and partly on a quarter sphere in object space projecting towards the camera. The central projection of this figure upon a vertical image plane results in lengthening the upper half of her body approximately 30% in relation to the lower half. Exactly the same distortion of proportions would occur in a good view camera, tripod-mounted at floor level, with vertical image plane and with the front lensboard racked up for photographing the apse mosaic without vertical perspective in the adjacent architectural elements. An art historian, studying a photograph of the apse, might talk about the special spiritual quality of the Madonna in Ossios Loukas gained from the artist's attenuation and distortion of her figure. These proportions, however, only exist in a photograph, and are not what actually appears at the entrance to the nave of Ossios Loukas to a beholder whose gaze is angled upwards directly towards the Madonna. A more accurate representation, an orthographic projection drawn within the Wild A7 Autograph upon a plane inclined 25° from the vertical, is illustrated in figure 26A.

Figure 25: Monastery Church of Ossios Loukas, near Delphi, Greece. This is the right photograph of a stereopair, taken with a Hasselblad Supreme Wide Angle camera, looking from the nave of the church towards the apse. The mosaic representation of the Madonna is drawn upon a quarter-sphere or semi-dome; and the projection of this form upon a vertical image plane results in lengthening the upper half of her body approximately 30 percent in relation to the lower half. This phenomenon can be seen more clearly in figure 26. Perry Borchers, 1960.

Figures 26 and 26A: A comparison of proportions in two drawings of the mosaic of the Madonna and Child in the apse of the Monastery Church of Ossios Loukas, Greece.

Figure 26 enlarges a segment of the photograph in figure 25, and shows the distortions occuring in a fine wide angle camera or—similarly—in a good view camera, tripod-mounted at floor level, with the front lensboard racked up for photographing the apse without vertical perspective in the adjacent architectural elements. This distortion is corrected in figure 26A, produced in a plotting instrument by orthographically projecting the optical model of the Madonna upon a plane inclined forward 25° from the vertical. This plane is perpendicular to the line of sight of a person focusing his gaze upwards the apse mosaic. The Ohio State University, 1966.

In other situations, the coordinate system in the Wild A7 Autograph easily and effectively replaces difficult and time-consuming work at an irregular site to establish coordinate systems for measurement.

Aerial Stereophotogrammetry of Architectural Subjects—Aerial photography must generally be taken from heights exceeding 1,500 feet above inhabited areas, and the relatively small scale of drawing and the lesser accuracy attainable from this distance limits the use of aerial photography in recording individual architectural subjects. Aerial photography, however, may be effectively used in a number of situations involving groups of buildings and their relationship to each other.

Since 1970, the Institut Géographique National of France has been mapping and drawing entire historic districts and towns in section and elevation from aerial photography (illustrated in figure 27). The French purpose in the photogrammetric recording of historic districts is to prepare drawings showing the architectural volumes, or, in their own term, **geometrals,** of the buildings of a historic district. From ground photography, an architectural draftsman could add the detail as seen in the left half of figure 27.

Any builder wishing to construct a new structure in such an area must first have the façades of the proposed building incorporated into the existing drawings for a determination of the effect of the new building upon the character of the district.

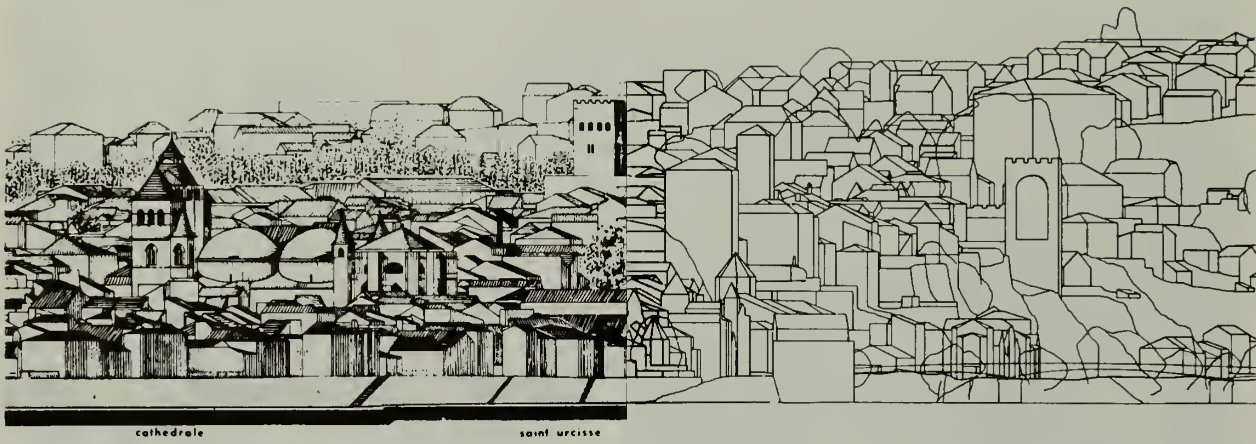


Figure 27: Partial drawing of the City of Cahors, France. Since 1970, the Institut Geographique National of France has been mapping and drawing entire districts and towns in section and elevation from vertical aerial photography. The visual effect of proposed new construction on the city can be determined by incorporating facade drawings of the proposed buildings into the existing section and elevation drawings. Institut Géographique National, 1972.

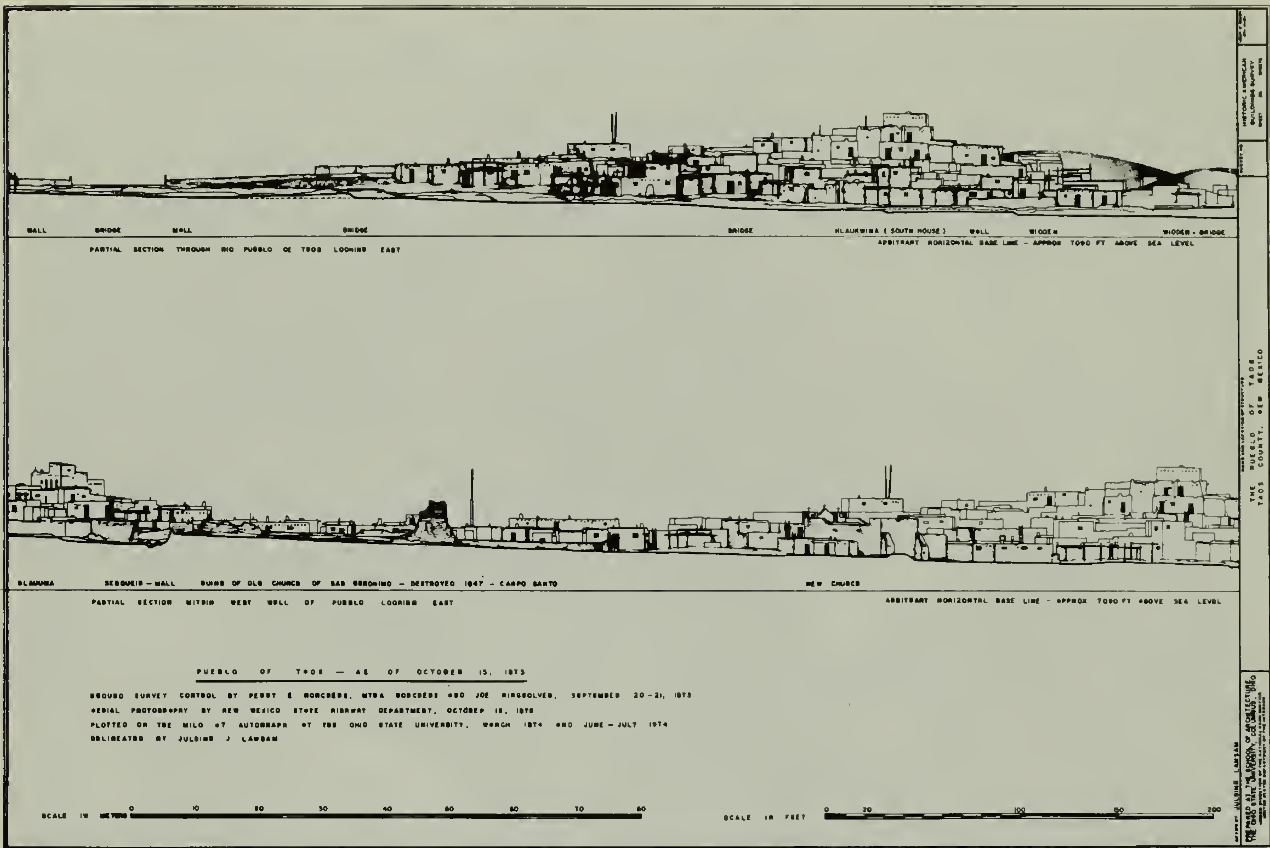
More recently, the Institut Géographique National has made geometric studies of the allowable heights of buildings in distant parts of Paris so that new construction will not obtrude upon the historic views of Paris as seen from the gardens and walks along the Seine.

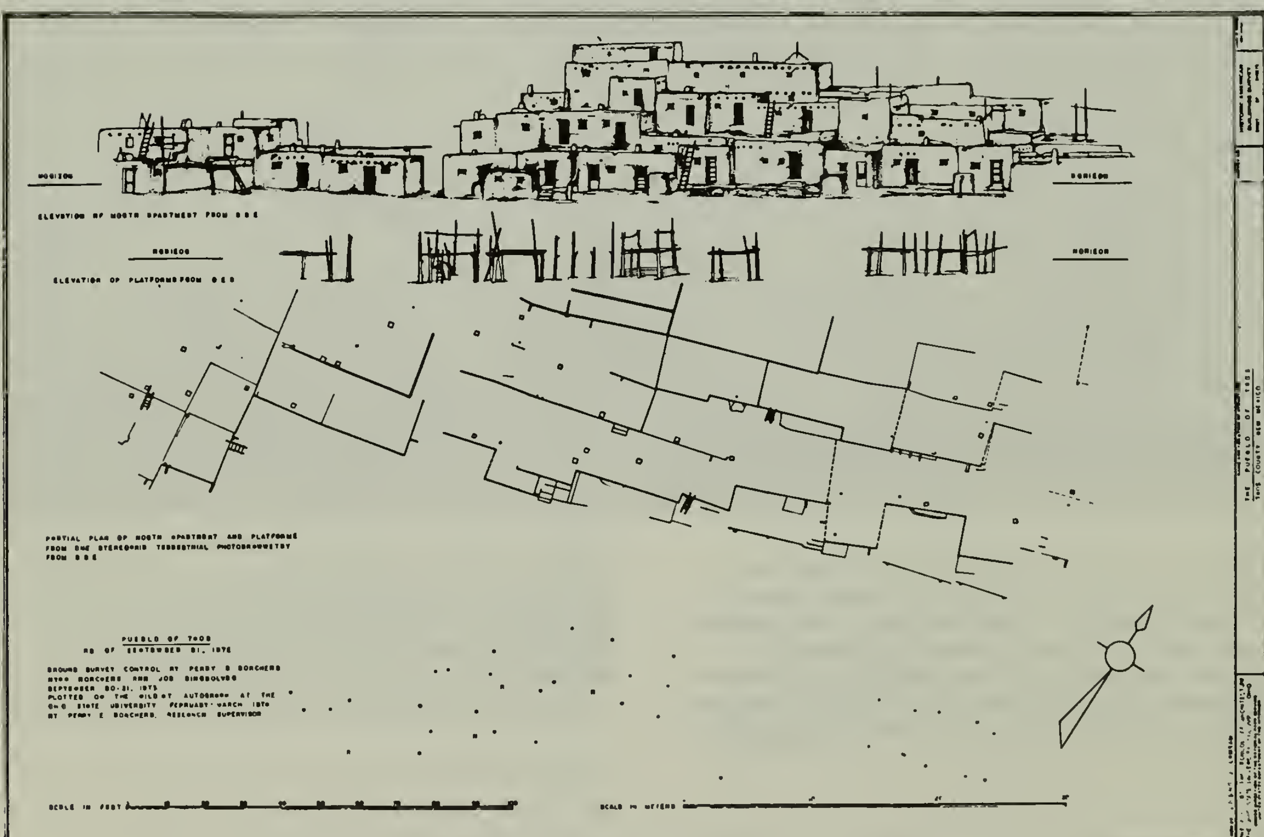
Since 1971, there have been a series of aerial recordings of the Indian pueblos of the Southwest, under joint sponsorship of the State Planning Office of the State of New Mexico and the Historic American Buildings Survey, and during 1975, the old Spanish towns of the upper Pecos River Valley, New Mexico, were also recorded by aerial photography for the Historic American Buildings Survey. Figure 28 shows a typical aerial photograph of the pueblo of Santa Clara in New Mexico. The pueblo is recorded from four lines of flight outside the perimeter of the central pueblo, so that there will be oblique views of the walls of the buildings. These views will allow the plotting of windows and doors and projecting beams in section and elevation drawings.

Figure 29A shows two sections through the pueblo of Taos in northern New Mexico drawn from aerial photography of this type. This drawing may be compared with figure 29, which is based upon ground photography in Taos taken with a phototheodolite. The buildings in figure 29 are at larger scale, with more detail, except where portions of the buildings, particularly in the partial plan drawing, are shielded from view from the ground camera stations.

In the case of the pueblo of Taos, the terrestrial photogrammetry provided the survey control necessary for orienting and scaling the aerial stereopairs. This is further evidence of the interdependence of the systems of measurement used to record cultural resources.

Figure 28: Aerial photography of the Santa Clara Pueblo, New Mexico. The historic central pueblo, at the upper boundary of this photograph, was recorded from four lines of flight around the perimeter to provide oblique views of the building walls. Managers of cultural properties should not overlook the fact that their property may have already been photographed from the air, either by the military, the U.S. Geological Survey, or a state highway department. It would be rare, however, to find aerial photography taken at this minimum altitude of 1500 feet above the subject. Photographed by the New Mexico State Highway Department, 1972, for Perry E. Borchers and HABS.





Conclusions

As has been shown in the preceding examples, photogrammetry is a viable means of recording historic architecture and cultural resources, and photogrammetric techniques can be used in a wide range of situations, from recording a single detail, such as the archway of the Old Chicago Stock Exchange Building, to entire districts, such as the pueblo at Taos, New Mexico. The advantages of using photogrammetry for recording historic architecture are many; details or architectural elements, often inaccessible for hand measurement, can be recorded with ease using photogrammetric techniques. A small team of photogrammetric experts can generally obtain survey data necessary to produce scale drawings in less time than a team using traditional, hand measuring techniques. This data can then be plotted to produce an economical and reasonably accurate record of the subject.

Where the most exacting standards of accuracy are required, however, elaborate and expensive provision for survey control and data adjustment computations are necessary and costs may rise dramatically. In some instances, it may be found that the expense involved in employing specially qualified architect-surveyors with costly equipment is out of proportion with the results needed. The choice between photogrammetric and hand measurement of a historic building depends on a number of factors, among them:

—what degree of accuracy is required in measuring?

—are large portions of the building(s) inaccessible for hand measurement?

—does the recording have to be completed quickly?

—would topographic, rather than planimetric, drawing of the subject be useful?

—are there large areas of complex detail that would prove time-consuming to hand measure?

—are qualified personnel available to operate the precise photogrammetric instruments and to select the most appropriate points for measurement of survey control?

Figures 29 and 29A: Taos Pueblo, New Mexico. Figure 29 was based on ground photography taken with a phototheodolite, while figure 29A was plotted from aerial photographs, with survey control provided by terrestrial photogrammetry. By combining techniques, it was possible to secure the survey control and photography necessary for drawing the entire pueblo in plan and elevation during a few minutes in the air over the pueblo and during approximately three hours on the ground within it. Aerial photography by the New Mexico State Highway Department, October 1973, and terrestrial photography and ground survey control by Perry and Myra Borchers and Joe Kingsolver, September 1973, for HABS.

The decision about what to record by hand or by photogrammetric techniques is one to be made carefully. Time, accuracy, cost, and amount of detail will determine whether simple, traditional techniques are sufficient or whether precise instrumentation is necessary.

This report has set out to show the wide range of applications of photogrammetry to the recording of cultural resources. Numerous case studies have shown the importance of reliable survey data in making an accurate and economic assessment of the means necessary to restore or insure the stability of a building. As a means for obtaining this data, photogrammetry can be a useful—and often indispensable—tool for the architect and engineer.

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